ENVIRONMENTAL
Objectives and Procedures for
WATER CROSSINGS

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MOE Technical Report 6

ENVIRONMENTAL OBJECTIVES AND PROCEDURES FOR WATER CROSSINGS

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PLANNING AND ASSESSMENT BRANCH

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ABSTRACT

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A properly designed water crossing that is carefully installed and well protected will minimize adverse impacts on fish and the aquatic environment. Legislative requirements and environmental concerns at crossings are presented in this report along with procedures for the installation of bridges, culverts, fords, causeways and pipeline water crossings. These procedures are designed to achieve the following objectives:

1. maintenance of natural stream conditions,
2. provision of fish passage,
3. prevention of pollution,
4. minimization of sedimentation, and
5. preservation of riparian vegetation.

The intent of these objectives and procedures is to foster flexibility in project planning and construction to achieve environmental protection in a wide range of field conditions. Activities such as site selection, design, scheduling, construction, maintenance and abandonment of a crossing are considered in so far as such operations pertain to environmental protection. Consultation with the appropriate government agencies will ensure that environmental concerns are addressed in the design and installation of such structures.

PREFACE

This report provides objectives and procedures to avoid environmental problems during the construction of water crossings. Intended for use in project development, this report is a guide to environmental protection. Those objectives which have a legislative requirement are indicated in the text.

The Planning and Assessment Branch, Ministry of Environment, produced these objectives under the authority of the Environment Management Act, Section 2(e). Guidance and direction was provided by an interministry committee composed of representatives from the Ministries of:

Energy, Mines and Petroleum Resources
Environment
Forests
Lands, Parks and Housing
Transportation and Highways

These objectives and procedures will be refined and updated as new techniques and information become available. User comments are welcomed.

ACKNOWLEDGEMENTS

Appreciation is extended to:

Dr. R.W. Lanford who initiated this project, coordinated the preparation of the report, provided editorial comments and chaired the Water Crossings Advisory Committee.

Peter Zimmerman, who drew the graphics.

Staff of the Ministry of Environment regional and Victoria offices, other government agencies and private consultants who gave valuable time to review and comment on earlier drafts.

The members of the Water Crossings Advisory Committee: Mr. D.S. Cameron, Ministry of Forests; Dr. T. Cockburn, Ministry of Lands, Parks and Housing; Mr. D.M. Galbraith, Ministry of Energy, Mines and Petroleum Resources; and Mr. M. Kent, Ministry of Transportation and Highways.

Any errors or omissions remain the responsibility of the writers.

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1. INTRODUCTION

1.1 PURPOSE AND SCOPE

This report provides objectives and procedures for maintaining environmental quality during construction of projects which affect watercourses. It serves as a guide for design engineers, construction supervisors, maintenance personnel and others who require practical information about environmental protection at water crossings.

Aspects of water crossings examined in this report include planning, design, construction, maintenance and abandonment. The types of water crossings considered are culverts, bridges, causeways, fords and pipelines. Much of the information presented is drawn from scientific literature, industry expertise and guidelines and measures used elsewhere. A bibliography is appended.

While it is desirable to maintain flexibility to establish water crossing requirements according to site-specific conditions, there are general environmental techniques and procedures available for minimizing disturbance to streams. This report is primarily concerned with these environmental aspects. Engineering design criteria and standard construction procedures are discussed where they have environmental implications. To be useful and effective, the procedures recognize economic and construction realities. Important factors are presented for consideration, in recognition that site-specific circumstances may require a solution unique to that location.

These objectives and procedures are not intended to supplant or infringe upon the responsibilities and authorities of other government agencies. Consultation by the project developer with such agencies is of prime importance.

1.2 ORGANIZATION AND USE OF REPORT

The report begins with introductory sections informing the user of legislative requirements for water crossings and of environmental concerns associated with water crossing work. This material provides a general background for subsequent chapters. Aspects common to all types of crossings are covered in Sections 2 to 7. Sections 8 to 12 deal with those aspects specific to each type of crossing. Section 13 is a glossary of technical terms used in this report.

2. LEGISLATIVE REQUIREMENTS AT CROSSINGS

Environmental legislation and assorted regulations have been designed to protect streams and their biota from deliberate or careless damage and destruction.

2.1 LEGISLATION

Any person or company wishing to affect surface water in any way is required, with few exceptions, to obtain authorization under the Fisheries Act of Canada and the Water Act of British Columbia.

The federal Fisheries Act requires a review of any proposed activity which may disturb or destroy fish, their habitat or their eggs. Developers are obligated to ensure the safe passage of fish past any project that will use or change the natural flow of any river or stream.

The primary purpose of the B.C. Water Act is to allocate and regulate the use and diversion of water. This is done to protect the environment, to protect the rights of other licenced users and to mimimize flood damage. The Water Act requires that a developer obtain a Water Licence or Water Approval before work is done in or around a stream.

The use of Crown land for development purposes requires authorization under the B.C. Land Act. Lake and stream beds are also Crown provincial land.

The B.C. Gravel Removal Order of the federal Fisheries Act protects spawning areas by regulating the removal of gravel from, or displacement of gravel within, the normal high-water wetted perimeter of any waterbody that is frequented by fish. Such activities require authorization and a written permit issued by a federal Fisheries Officer. Additionally, all gravel removal from Crown land, whether instream or not, requires authorization under the Land Act.

The federal Navigable Waters Protection Act requires that any structures over navigable water have a clear span from normal high-water levels that will allow passage of craft which may use these waters.

Some municipalities have also enacted bylaws under the Municipal Act, to restrict development near or alterations to local streams and watercourses. It may be necessary to obtain authorization from the municipal engineering department or other designated authority for operations conducted within a municipal boundary.

2.2 WATER LICENCES

Water is a Crown-owned resource managed by the Ministry of Environment. Permission to use surface water is obtained by means of a Water Licence. This licence is a legal document which is issued by the Comptroller of Water Rights and which specifies the conditions governing the right to the use of water. Licences are issued for domestic use, irrigation, mining, industrial use, power generation storage and other purposes.

2.3 WATER APPROVALS

The Comptroller of Water Rights or Regional Water Manager may, without issuing a licence, grant an Approval under Section 7 of the Water Act for short-term use of water or changes in and about a stream. Conditions attached to the Approval may apply to fisheries or environmental protection. Approvals for changes in and about a stream may be required for such activities as protecting streambanks, altering the channel of a stream, filling or excavating land adjacent to a stream or ditch, and placing a bridge, culvert, pipeline or other structure within, over or under a stream channel.

It is neither practical nor necessary to issue a Water Approval for every stream crossing. Decisions regarding licences and approvals are made on a site-specific basis by staff of the Water Management Branch. Inquiries should be directed to the Regional Water Manager, Ministry of Environment (Table 1).

TABLE 1

REGIONAL OFFICES - MINISTRY OF ENVIRONMENT

REGION 1 - Vancouver Island

2569 Kenworth Road
Nanaimo, B.C. V9T 4P7
Telephone: 758-3951

REGION 2 - Lower Mainland

10334 - 152A Street
Surrey, B.C. V3R 7P8
Telephone: 584-8822

REGION 3 - Thompson-Nicola

1259 Dalhousie Drive
Kamloops, B.C. V2C 5Z5
Telephone: 374-9717

REGION 4 - Kootenay

310 Ward Street
Nelson, B.C. V1L 5S4
Telephone: 352-2211

REGION 5 - Cariboo

540 Borland Street
Williams Lake, B.C. V2G 1R8
Telephone: 392-6261

REGION 6 - Skeena

3726 Alfred Avenue
Smithers, B.C. V0J 2N0
Telephone: 847-4411

REGION 7 - Omineca-Peace

1011 Fourth Avenue
Prince George, B.C. V2L 3H9
Telephone: 563-1181

REGION 8 - Okanagan

3547 Skaha Lake Road
Penticton, B.C. V2A 7K2
Telephone: 493-8261

Note: Some regional names and boundaries may be changing in the near future.

2.4 FISHERIES AGENCIES APPROVAL

In addition to obtaining a water licence or approval, anyone planning to build a structure across fish-bearing waters is required to contact the appropriate fisheries agency having jurisdiction in that area. The species of fish that resides in, or periodically uses, the waterbody to be crossed determines which agency is to be contacted.

In British Columbia, the Fish and Wildlife Branch of the provincial Ministry of Environment is responsible for the management of all freshwater fish and anadromous species other than salmon. The federal Department of Fisheries and Oceans is responsible for tidal or saltwater fishes including all 5 species of Pacific salmon. Legislative authority for both agencies is provided by the federal Fisheries Act. Either agency can advise developers on the jurisdictional aspects of any stream or river in question.

Proposals for work involving instream activities should be submitted to the appropriate agencies at the earliest possible stage for their review and comments. Initial contacts can be made at the following level:

1. Provincial Fish and Wildlife Branch - by advising the regional office having jurisdiction in that area.
2. Department of Fisheries and Oceans Canada - by advising the district office having jurisdiction in that area. Table 2 lists addresses of Department of Fisheries and Oceans district offices.

Upon initial contact, the agencies will assess the water crossing proposal to:

i. determine if there is a fisheries resource to be protected;
ii. confirm whether their involvement and approval will be required;
iii. ascertain the impact of the crossing on the fisheries resource.

TABLE 2

DISTRICT OFFICES - FISHERIES AND OCEANS CANADA

(PACIFIC REGION)

DISTRICT 1 - Kamloops

202-317 Seymour Street
Kamloops, B.C. V2C 2E9
Telephone: 374-4322

DISTRICT 2 - New Westminster

309-549 Columbia
New Westminster, B.C. V3L 1B3
Telephone: 524-7181

DISTRICT 3 - Nanaimo

60 Front Street
Nanaimo, B.C. V9R 5N7
Telephone: 753-4181

DISTRICT 4 - Port Alberni

Box 280
Federal Building
Port Alberni, B.C. V9Y 7M7
Telephone: 724-0195

DISTRICT 5 - Campbell River

215-950 Alder Street
Campbell River, B.C. VOW 2P8
Telephone: 287-2102

DISTRICT 6 - Victoria

116-816 Government Street
Victoria, B.C. V8W 1W9
Telephone: 388-3252

DISTRICT 7 - Kitimat

315-450 Federal Building
Kitimat, B.C. V8C 1T6
Telephone: 632-4884

DISTRICT 8 - Prince Rupert

109-417 2nd Avenue West
Prince Rupert, B.C. V8J 1G8
Telephone: 624-9137

DISTRICT 9 - Queen Charlotte Is.

Box 99
Queen Charlotte City, B.C.
VOT 1SO
Telephone: 559-4413

After these initial contacts, the project developer can design the water crossing incorporating information received from the fisheries agencies and from procedures contained within this document. The final design should be sent to the involved fisheries agency. Detailed designs of water crossings, including the drawings, should provide sufficient information to allow a close examination of the crossing structure, its hydraulic characteristics, and its effects upon the adjacent stream areas. Additional information may be required on the hydrological characteristics of the watershed, criteria used in selecting the crossing structure, proposed construction method and scheduling.

The project developer must notify the involved fisheries officer(s) at least 5 working days prior to the start of installation of the water crossing. This officer is also to be informed no less than 5 days prior to anticipated completion of the crossing to permit final inspection.

2.5 CROWN LAND EASEMENTS

Under Section 37 of the B.C. Land Act, the use of Crown land for linear development purposes must be legalized by way of an easement or right-of-way. Other related construction activities on Crown land such as campsites or wastedumps will also require authorization under the Land Act. Applications should be submitted to the District Manager of the Land and Housing Regional Operations Division, Ministry of Lands, Parks and Housing. A development plan and other information may be required.

2.6 REFERRALS

There is an interagency referral process for reviewing applications under the Water Act in which concerned agencies have an opportunity to evaluate the proposed activity. As a statutory requirement under Section 8 of the Water Act the Comptroller or the Regional Water Manager notifies the Deputy Ministers of Agriculture and Food, and Lands, Parks and Housing of the receipt of each application for the licence. Under Section 9 of the

Water Act, legitimate objectors to the granting of an application may be another licencee, riparian owner or applicant for a licence who considers that his rights would be prejudiced by the granting of an application for a licence, or the Deputy Attorney General, the Deputy Minister of Lands, Parks and Housing or the Deputy Minister of Agriculture.

In addition to the above, the referral process for reviewing applications includes the following agencies:

a. the local municipality and regional district with respect to drainage plans;
b. the Fish and Wildlife Branch with respect to effects of the project on wildlife or fish under provincial jurisdiction;
c. the Department of Fisheries and Oceans with respect to possible impacts on fish under federal jurisdiction;

These agencies will assess the proposal and will advise the Water Management Branch of their concerns. Constraints such as the provision for fish passage or time periods for construction activities may be incorporated as legal conditions of the Water Approval or Water Licence. Requirements of the federal Fisheries Department will be given directly to the applicant, or could be incorporated as a legal condition of the Water Approval or Licence.

Developers are urged to contact the Ministry of Environment at the earliest opportunity to ensure that the proposed design and construction of water crossings conform to all pertinent Acts and Regulations.

2.7 PENALTIES FOR NON-COMPLIANCE

Water must not be removed, used or diverted from a watercourse without having obtained prior authorization. Persons who are engaged in construction activities affecting watercourses without having first obtained authorization for the activities or who are not complying with the conditions of an authorization are liable for prosecution under the B.C. Water Act or the federal Fisheries Act. Penalties include suspension of operations, fines or imprisonment.

3. ENVIRONMENTAL CONCERNS AT WATER CROSSINGS

Any water crossing has the potential for detrimental impacts on water quality and consequently on non-consumptive and consumptive water users. Such disturbances occur during construction and can also result from poor maintenance or underdesign. Any alteration to the natural channel configuration can lead to increased bedload movement and suspended sediment levels which can affect fish and their habitat and have undesirable effects on the quality of water used for domestic, irrigation and industrial consumption. Certain types of crossing structures can be an obstruction to the passage of wildlife. Potential impacts of various types of crossings on consumptive water users, fisheries and wildlife are described in the following sections.

3.1 HUMAN USE

Water with high sediment loads or toxic materials can be unfit for human consumption and require costly filtration to be suitable for industrial use. Muddy, brown streams have a considerably reduced aesthetic appeal and, as more people use wilderness areas, maintaining water quality has an increasing importance. High sediment loads also reduce the recreational value for swimming, boating and fishing.

Improperly installed crossings can increase risk to human life and property through flooding and debris transport. Culverts and bridges which are not designed to pass a large enough flow, or those which become plugged with debris through faulty design or improper maintenance, can cause severe upstream flooding or downstream erosion from changed streamflow. If the fill should fail or the debris plug suddenly release, debris flow damage or downstream flooding can occur as well.

3.2 FISHERIES

3.2.1 BLOCKING FISH PASSAGE

Upstream fish movement depends on the age, sexual maturity and swimming ability of the species concerned and on the hydraulic conditions of the stream. Any construction activity that severely alters the stream flow or adversely changes the characteristics of the streambed may be detrimental to fish passage.

Culverts can block the upstream movement of fish if the water velocity is excessive, if the outlet is too high above stream grade, or if there is no pool below the culvert for fish to gain the necessary momentum for the jump (Figure 1). Erosion protection, such as riprap, improperly placed at the outlet may impede fish passage. Oversized culverts can create stream flows which are too shallow for fish passage, while undersized culverts may be susceptible to debris jams or washouts which may in turn obstruct fish passage or destroy habitat.

Other types of crossings can be equally detrimental. Improperly placed bridge abutments can block fish passage by increasing stream velocity. Fords and pipeline crossings can alter the natural river bottom such that fish passage is blocked during low-flow periods. Causeways that only allow water flow by means of seepage completely block fish passage, as do many other dam-like structures placed in a stream.

3.2.2 CAUSING FISH MORTALITY

During construction of a crossing facility, the physical disturbance of the watercourse and surrounding land can result in the discharge of sediment and pollutants into the stream. Scour from an improperly designed crossing can also result in an increased sediment load to a stream.

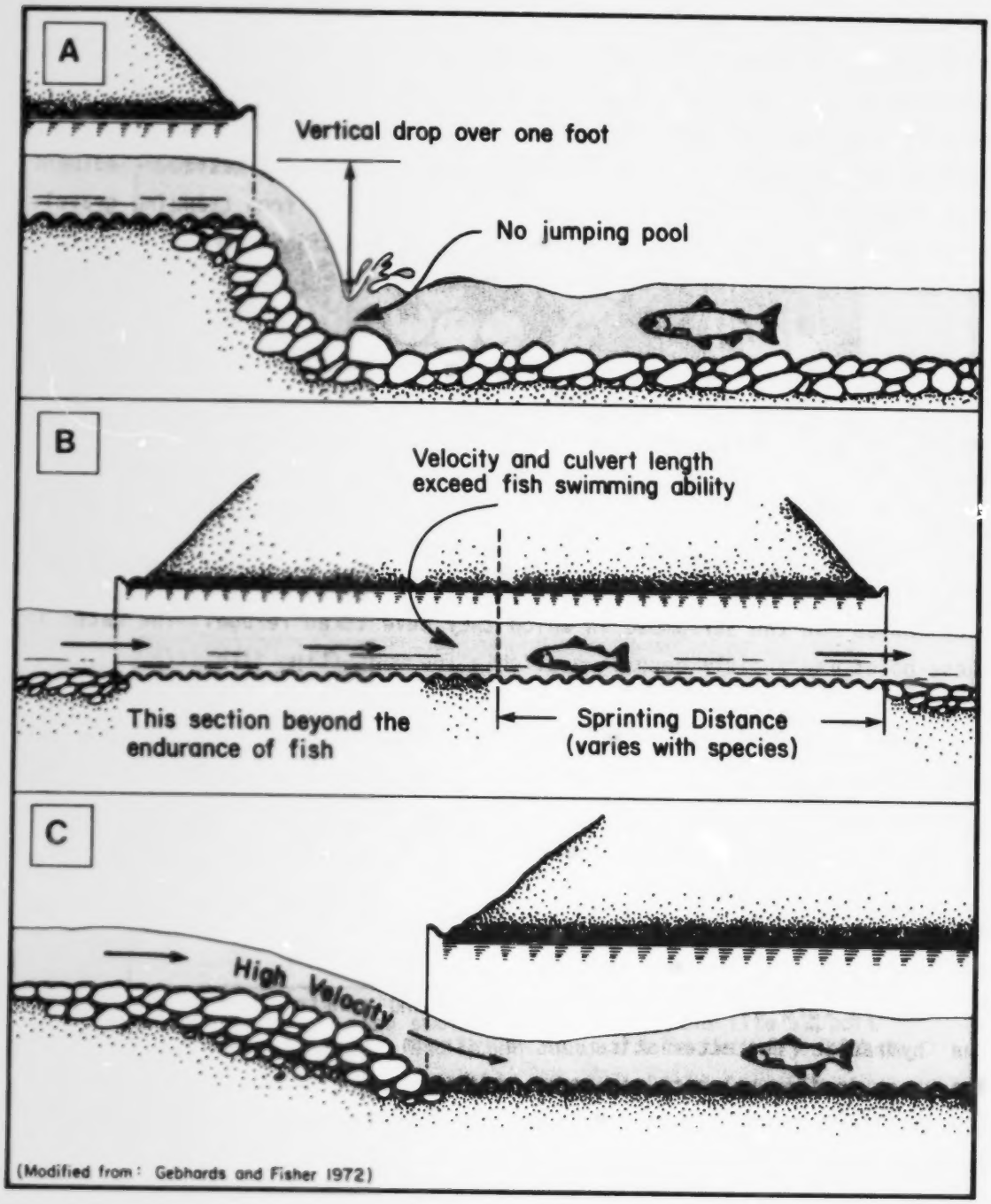


FIGURE 1 Culverts That Block Fish Passage

In suspension, sediment abrades or clogs the sensitive gill membranes of young fish, causing injury or suffocation. Sediment also reduces the penetration of light, impairing food production. On spawning gravel, sediment inhibits subsurface water circulation, thus depriving incubating fish eggs of oxygen and obstructing the withdrawal of metabolic wastes. Sediment also hampers or prevents the emergence of hatched fish from spawning gravel. After the emergence of fry, excessive sediment makes finding food difficult, thereby inhibiting fish survival and growth (Figure 2).

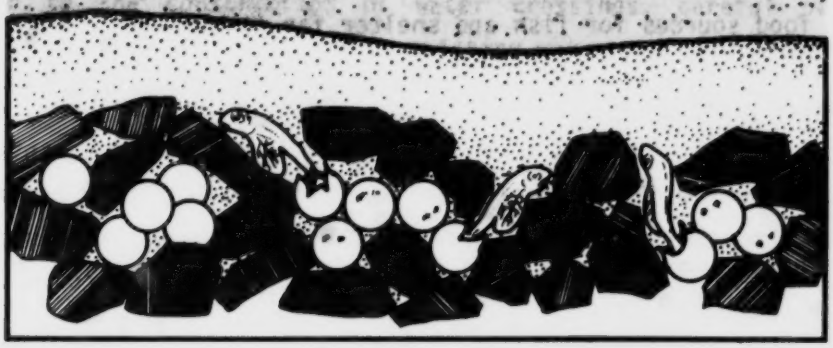
Work in and around the stream can introduce pollutants that are toxic to fish and aquatic life. Pollution can come from machinery (oil, gas, diesel fuel, grease), construction materials (concrete, lime, creosote, asphalt), or organic debris (bark, wood chips, topsoil, sawdust, ashes).

The diversion of a stream can trap fish in a cut-off section of the stream channel. Even with a temporary diversion, fish can become trapped in deep "holes" in the streambed in which they have taken refuge. The water in these holes may rapidly become unsuitable for supporting fish life.

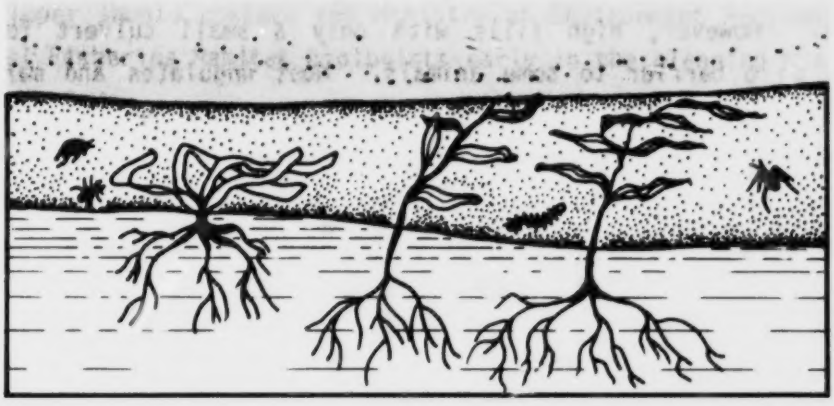
Near-stream or underwater blasting represents a hazard to fish and other aquatic populations. In addition to such direct effects as injury and mortality, blasting can affect bank stability and may increase stream siltation.

3.2.3 DESTROYING FISH HABITAT

Unless care is taken with the design and construction of a crossing, the hydraulic characteristics of a stream may be adversely changed. Increases in flow velocity can cause shifts and downstream transportation of stream gravel which disturbs or destroys spawning beds, rearing areas for juvenile fish, and other aquatic habitat.



A Sediment can cause suffocation of the fish eggs and fry or prevent fry from wiggling free of the gravel.



B Sediment can also smother and kill off the life support system of insects and other aquatic life that fry feed on.

FIGURE 2 Adverse Effects of Sediment

Large-scale removal of vegetation immediately adjacent to a stream can increase water temperature. This may be directly lethal to salmonids, may contribute to increases of parasitism and disease, or may allow coarse fish to invade salmonid habitat. Removal of this vegetation also reduces both terrestrial food sources for fish and shelter for fish to avoid predators.

Vegetative growth along streams filters surface runoff water, removing forest litter and much of the suspended sediment. In addition, this growth can protect streams from dust, salt and other pollutants introduced by the proximity of roadways. Finally, well-rooted riparian vegetation stabilizes the streambanks and shorelines and protects these areas from erosion.

3.3 WILDLIFE

Land adjacent to a stream, especially in steeper valleys, is often used by wildlife as a travel corridor. Most ungulates, such as deer and elk, will pass under a bridge, particularly during low flows when there may be a dry passage. However, high fills with only a small culvert for water passage may be a barrier to some animals. Most ungulates and many small mammals will climb a fill and cross the road to continue their travel. Increased vehicle-animal collisions may result and, if the road is to have extensive use, this factor may make a bridge or large, bottomless arch pipe more economically feasible as well as environmentally desirable. In fact, certain bridge designs may encourage wildlife passage under a bridge thereby reducing the possibility of vehicle-animal collisions and creating safer conditions for road users.

Construction of roads or pipelines through marsh or wetlands can affect wildlife habitat. Even though there may be no appreciable current, cross-drain culverts in fills must be provided to avoid either drying out marshland and destroying forage and refuge, or flooding areas which are used for wildfowl nesting. Altered flow patterns or water volumes may directly affect aquatic wildlife such as beaver or muskrat.

4. PLANNING CROSSINGS

Prior to the construction of water crossings, careful planning is required to determine how changes to existing water and land features can be accomplished with the least harmful effects.

4.1 CORRIDOR LOCATION

In the planning of any linear facility, such as a road, pipeline, railway or transmission line, normally only the end points are fixed. There may be several corridors through which the facility could be located and the choice should be made based on a comparison of the economic, social and environmental costs of using each corridor. It is essential that the potential environmental impacts within these corridors are fully understood in order to make an informed choice. For information and assistance, a project developer should contact the Ministry of Environment Regional Director and federal Fisheries Habitat Biologists early in the planning stage.

4.2 ROUTE SELECTION

Within a given corridor, there may be some flexibility regarding choice of a specific route. Every water crossing represents increased costs for construction, maintenance and environmental protection requirements. Therefore, whenever possible, minimize the number of water crossings and avoid sensitive wetland areas or routes immediately adjacent to watercourses.

Once the final route is chosen, plan each water crossing on a site-specific basis. The location and timing for installation will affect not only the design but also the construction method, the environmental protection measures and the maintenance requirements.

Where there is a choice among streams to cross, select that stream which:

a. is already subject to natural siltation,
b. has minimal fish values, or
c. has no licenced water users.

When there is a choice between alternative crossing sites on a stream, locate the crossing:

a. downstream from areas such as fish spawning sites or water use intakes;
b. above natural fish barriers such as waterfalls;
c. where the stream is straight, unobstructed and well defined;
d. on an existing right-of-way if one exists;
e. where stable geological and soil conditions are present;
f. where a minimum of scour, deposition or displacement of sediments are expected to occur at or near a crossing;
g. where possible effects on other existing bridges and hydraulic structures can be avoided;
h. where it is possible to minimize the risk of damage from environmental hazards such as floods, landslides, avalanches, or subsidence; and
i. where aesthetic conditions are favourable.

4.3 SCHEDULING

As much as possible, schedule the installation of water crossing structures to avoid instream work during periods of high environmental sensitivity such as fish migration, spawning, fish egg incubation, fry emergence and waterfowl nesting.

It is imperative that fish migration not be impeded and that spawners and incubating eggs not be disturbed. Blockages or stream disturbances resulting from construction may not be permitted during such periods. It is best to consider the stream and fish population on a system-specific basis. Periods of sensitivity will vary with the species involved and the geographic location. In general, there are two critical time periods involved

in this regard, one for spring spawning species and one for fall spawners. Timing constraints may be imposed accordingly by fisheries agencies.

When possible, construction of water crossings should take place during seasons or periods of low wildlife and waterfowl occurrence; for example, construction in the vicinity of wetlands should be avoided during waterfowl nesting and migration.

4.4 ENVIRONMENTAL PROTECTION DURING CONSTRUCTION

The effectiveness of environmental protection during construction will be greatly enhanced with the following practices:

a. Ensuring that environmental concerns have been incorporated in the plans and specifications for the project. These documents should be explicit in describing the location, scope and manner of carrying out environmental control measures as set out by the Ministry of Environment or other government agencies.

b. Informing supervisory staff and construction workers of these concerns and details. It is essential that construction workers be made aware of the need for environmental protection and be encouraged to actively participate in it.

c. Supervising the environmental, as well as the engineering aspects of construction activities. Environmental supervision provides the necessary follow-up to planning. In addition, supervision is required to detect and correct environmental problems that arise from unforeseen circumstances and to make alterations when designed protection measures are not working out as expected.

5. DESIGN CONSIDERATIONS

5.1 DESIGN FLOW AND WATER LEVEL

To design an adequate crossing and construct it at the least damaging time, it is essential that the flow regime at the crossing location be determined. The important flow characteristics are the timing and magnitude of the annual peak and low flow period and the range in flows which may be encountered. Also of concern in some regions are the dates of freeze-up and break-up and the potential for blockage of culverts due to freezing.

The streamflow characteristic of major importance is the peak or flood flow usually related to a certain probability of being equalled or exceeded in terms of a "return period". Determining a design peak flow with a certain return period allows one to assess the probability that a crossing structure could be damaged or destroyed within a selected time period. For example, a 50-year return period peak flow will be equalled or exceeded, on the average, once in a 50 year period. The probability or risk of a 50-year return period peak flow occurring in the 25-year "life" of a structure is about 40%; the probability of a 100-year return period event occurring is about 22%.

The main source of data for the analyses used to estimate peak flow is the hydrometric station network operated by Water Survey of Canada. The peak flow magnitude can be estimated by regionalization methods, or empirical formulae which relate peak flow to precipitation input. The method used will depend on the climate, watershed characteristics (especially drainage area) and the data available. The Surface Water Section, Water Management Branch, conducts an Peak Flow Regionalization program which includes summaries of peak flow information for gauged watersheds and procedures for estimating these flows.

Once the desired peak flow estimate is derived, this can be related to flow velocities for studies of erosion and scour potential, and used as input to analyses for determining the return period flood level or floodplain area. The Floodplain Planning and Surveys Section, Water Management Branch prepares 200-year return period floodplain maps for large rivers, and can provide advice on procedures for relating peak flows to corresponding water levels.

The published daily discharge (or hydrometric) data can also be used to estimate low flow characteristics, but such estimation for ungauged watersheds is much more difficult than for peak flows. Summaries and analyses of these data can also be provided by Water Management Branch.

5.2 EROSION

Scour and deposition are complementary aspects of the erosion process. This occurs when fast-flowing turbulent water removes particles from parts of the streambed or banks and deposits them at other parts. Higher velocity flows and lightweight, fine soils result in the greatest erosion.

Local scour is caused by obstructions in the flow which increase local velocity and, consequently, increase erosion. These obstructions might be natural, such as a large boulder, or artificial constructions, such as bridge piers and abutments. Local scour depth is in addition to any general scour and the total scour depth must be allowed for in any instream construction.

Material which is removed by the high velocity water will be deposited downstream where the channel is wider or deeper and the velocity reduced. This deposition can change the channel shape and may create sand or gravel bars which can also catch logs, causing log jams. Serious effects can result from water flow constrictions.

6. CONSTRUCTING CROSSINGS

In addition to the engineering requirements of constructing a crossing facility, the following five environmental objectives are desirable when working in and around streams or lakes:

1. prevention of pollution,
2. maintenance of natural stream conditions,
3. provision of fish passage,
4. minimization of sedimentation, and
5. preservation of riparian vegetation.

The following sections provide procedures to meet these objectives.

6.1 WORK IN AND AROUND STREAMS

Practices that will help to avoid or control pollution include:

a. Minimize equipment activity within the wetted perimeter of any stream. Ensure that hydraulic, fuel and lubrication systems are in good repair to avoid leakage.
b. Do not service machines adjacent to watercourses. Remove from the site and properly dispose of any waste oil, filters or garbage from servicing.
c. Do not store petroleum products in the vicinity of any watercourse or lake.
d. Do not wash any type of equipment or machinery in streams or lakes. Control waste water from construction activities, such as equipment washing or concrete mixing, to avoid discharge into any water.
e. Any aquatic plants uprooted or cut during excavation should be removed and disposed of on land in an approved disposal site. It is important that these plants not be deposited in another body of water. The following precautions will avoid introducing foreign aquatic plants into a watercourse:

i. Determine the existence of noxious weeds which construction equipment could carry forward from an infested to a clean area;

ii. If noxious weeds are known to be present in the area, hose down and thoroughly wash equipment before it proceeds from one area to the next.

6.2 TEMPORARY CROSSINGS

The environmentally preferred temporary crossing is one that can be launched from embankment to opposite embankment such as a Bailey bridge or log bridge. Remove log bridges and similar structures before the anticipated high water period. If a crossing is required during this high-water time, it must be designed to the same standard as a permanent structure. Upon completion of the use of any temporary crossing, remove all structures and restore the disturbed area to its original condition or to a stabilized condition that will not result in erosion or scour. Where vegetation has been disturbed, revegetate with plants native to the area.

6.2.1 ICE BRIDGES

Recommended construction practices:

a. Locate ice bridges so as to minimize approach grades. Do not unnecessarily cut stream banks to improve access.

b. Construct approaches of compacted snow and ice to a sufficient thickness to adequately protect the stream or river banks, including the vegetative cover on the banks.

c. Ice bridges must not interfere with or impede winter flows in any river or stream.

d. Regularly maintain ice bridges during use. Remove all debris from the ice surface and dispose of it outside the normal high-water wetted perimeter of the stream.

e. Remove ice bridges, if they have the potential to cause a blockage during the spring runoff.

6.3 CLEARING

In areas of wet or fine-grained soils, which are easily damaged by heavy machinery, it is recommended that clearing be done when the ground is frozen if possible. In all areas, avoid clearing during break-up, high runoff periods or any very wet times.

Application of the following precautions will reduce impacts caused by clearing:

a. Do not remove shoreline vegetation at river and stream crossings except where necessary for crossing facility installation and then only just prior to that installation.
b. Use hand clearing techniques if heavy equipment would jeopardize streambank stability.
c. Fell trees away from water bodies.
d. Do not use stream-side landings and keep all heavy equipment out of streams.
e. Do not skid logs across streams or use streambeds, even dry ones, for skidding logs.
f. Avoid long skids on steep slopes adjacent to watercourses.
g. Remove trees and debris that accidentally fall in a stream or body of water in a manner that will minimize disturbance to the streambed. Lift rather than skid these trees out of the stream.
h. Consult with the federal Habitat Biologist or Regional Habitat Protection Biologist before attempting instream work.

6.4 GRUBBING

Suitable practices to minimize effects of grubbing operations near streams are indicated below.

a. Dispose of cleared and grubbed material as soon as possible after removal. Do not place this material in or near the stream.

b. Immediately remove any material inadvertently placed within the normal high-water wetted perimeter.
c. Burn slash and organic debris in dispersed piles such that residual material will not be transported into the stream.
d. Divert to vegetated areas any sediment-loaded waters which accumulate on cleared and grubbed sites.
e. If necessary revegetate to control erosion.

6.5 STRIPPING

Recommended procedures to minimize sedimentation from stripping operations:

a. When stripping topsoil near a stream crossing, it is important not to disturb the ground near the stream until the actual start of crossing construction. A leave-strip of 30 to 100 m may be required depending on terrain.
b. Do not push stripping debris into any watercourse.
c. Do not place materials in areas where natural drainage or stormwater could pond or erode stripped materials and transport sediment into a watercourse.
d. Where stripping debris is pushed towards the edges of the right-of-way, leave gaps to channel runoff into the vegetation rather than allowing the water to flow along the right-of-way to the stream.

6.6 EARTHWORK

Measures to minimize unnecessary sedimentation from earthwork operations include:

a. Use blasted rock or clean granular material with riprap to construct any embankment that encroaches on any stream, lake or body of water.

b. Excess material (waste) if carelessly discarded can erode and cause damage to surrounding vegetation and watercourses. Deposit such material in a stable, flat location well above high water levels.
c. When fill material is to be stored for any length of time, place it in a well-drained, stable location away from any watercourses.

6.7 BLASTING

Contact the Regional Habitat Protection Biologist and federal Senior Habitat Biologist prior to any underwater or near-stream blasting.

Recommended practices to minimize risk to fish and fish habitat from blasting operations:

a. Strictly control all explosives used in construction.
b. Restrict their use to authorized personnel trained to minimize environmental damage.
c. Ensure the schedule, frequency and intensity of blasting consider the hazard to fish and fish habitat and are adjusted to mitigate the effects.

Normally, underwater blasting is not to take place within 400 m of areas where there are concentrations of fish eggs, fish spawning, rearing, migrating, overwintering or where native or extensive sport fishing is taking place. If this is not possible:

a. schedule blasting for periods when fish are not in the area of influence by blasting;
b. remove fish from the proposed blast site and restrict their access by stop nets;
c. use blast deflectors such as sandbags or bubble curtains; or
d. reduce the area of high blast concussion with special detonation techniques.

6.8 DRAINAGE CONTROL

6.8.1 APPROACHES TO CROSSINGS

The control of surface runoff at or around water crossings is an important environmental consideration. Surface runoff can erode soil and pick up sediment when flowing along approach ditches to a water crossing.

Incorporate one or a combination of the following measures in the design and construction of approaches to water crossings:

a. Avoid steep downhill approaches to prevent erosion from high-velocity runoff.
b. Ensure that ditch bottoms along approaches to water crossings are stable, preferably lined with non-erodible materials such as rock or crushed gravel. Drop structures or ditch plugs are effective methods of controlling runoff to prevent erosion in ditches.
c. Just before a major water crossing, intercept and divert the runoff into a sumphole, settling basin, or nearby vegetated areas.
d. Divert the runoff with diversion ditches at frequent intervals into suitable settling areas. Begin ditches far enough upslope from stream channels to allow adequate dispersion of runoff before entering the watercourse.
e. Use vegetation as a buffer and filter for silt-laden surface runoff.

6.8.2 GRAVEL PITS AND BORROW SITES

Regulate the drainage from construction areas and other work sites such as gravel pits or borrow sites to prevent the discharge of silt-laden water into adjacent watercourses.

Recommended procedures:

a. Wherever possible, avoid the removal of borrow material or gravel in the vicinity of a watercourse. Such activity requires authorization under the federal Fisheries Act and the B.C. Land Act.
b. During the excavation of material from borrow sites or gravel pits, control runoff and divert it to vegetated areas to filter the sediment. Depending on the size of the pit, it may be advisable to construct interceptor ditches for surface runoff above the pit area.
c. When the pit is no longer required, institute reclamation measures to avoid slumping and erosion.
d. Use closed-circuit gravel washing systems that incorporate settling basins to control siltation.

6.9 CHANNEL DIVERSIONS

Changes in channel geometry and location, such as the realignment of a stream, can have severe impacts on the adjacent natural stream system. In addition, valuable aquatic habitat may be lost as a result of by-passing the former channel. It is important to design and build the new channel in a manner that preserves these habitat values. Keep channel diversions and channelizations to a minimum and obtain authorization prior to construction from the regional offices of the Ministry of Environment and the federal Fisheries Department.

Diversions need to be designed on a site-specific basis. The following is one method that can be used to minimize the adverse impacts:

a. Design the new channel to be similar in width, depth and substrate material to the old channel. Make the new channel length as close as possible to the original, thus providing a similar slope. Ideally, the new channel is to have the same velocity and discharge where it ends as the old one had.

b. Avoid stream width constriction to prevent long term erosion problems. If constrictions are necessary and erosion problems likely to occur, then erosion control measures are necessary.

c. Ensure that water flow is not blocked during construction operations.

d. Leave the existing channel untouched until the new channel is completed.

e. Excavate and construct the new channel in the dry, beginning at the downstream end. Keep the upstream and downstream ends blocked off until the new channel is complete.

f. Remove the downstream plug and then divert the water into the new channel by removing the upstream plug.

g. Close off both ends of the old channel, fill and stabilize it. The existing channel should not be filled and blocked until diversion into the new channel is complete.

h. Prevent the entrapment of fish in the old channel. If fish do become trapped in isolated pools, immediately transfer them to the stream.

i. If a tributary stream enters the former channel within the diversion area, connect it in a suitable manner to the new channel.

j. Dispose of all the debris removed from the new stream channel far enough from the watercourse that high water will not return it to the stream channel. If the debris or excavated material is to be used to fill the former channel, store it near the area of future use, but not in the water.

k. Provide as much natural cover as possible along the new alignment and revegetate where necessary.

l. Riprap any areas subject to erosion.

m. Fisheries agencies may require instream and wetted bank measures such as boulder groups to provide holding areas and enhance fish passage in the new channel.

n. Ensure that the new channel provides fish passage when required during normal low flow periods.

7. CLEAN-UP AND REHABILITATION

7.1 STABILIZATION AND REVEGETATION

Water crossing structures should be protected and disturbed areas revegetated as soon as possible following construction. It is important to have stabilization measures in place to protect the ground cover, streambanks and crossing facilities during periods when erosion potential is high.

Stabilization measures:

a. Reshape all disturbed areas within the high-water wetted perimeter of the stream to their original configuration.
b. Restore all disturbed areas adjacent to the watercourse to finished, stable slopes. Slope stabilization practices may include: seeding, planting, mulching, placing mat binders, soil binders, rock or gravel blankets or terracing on long slopes.
c. Remove all construction debris and material from the crossing site (this includes any material deposited downstream from the crossing site as a result of construction).
d. Dispose of excess foundation excavation material away from the stream channel; smooth this and provide drainage so that heavy rain or high stream flows will not wash sediment into the stream.
e. Smooth, provide drainage and revegetate borrow and spoil areas as soon as practicable after construction is finished in each area.

Areas of erodible soils require riprap protection wherever they are subject to flowing water (Figure 3). The following measures will ensure these works are effectively installed:

a. Dress smooth the slopes of any areas to be protected and remove all stumps, organic matter and waste material.
b. The best material for use as riprap is clean (free from organic

matter), durable, angular rock with fractured faces and graded sizes (Table 3).

c. Provide a toe trench in which to key the bottom layer of protection.

d. Place riprap protection to its full thickness in one operation and in such a manner as to avoid displacing the underlying materials.

e. Provide a filter layer wherever it is anticipated that there may be migration of fines through the riprap.

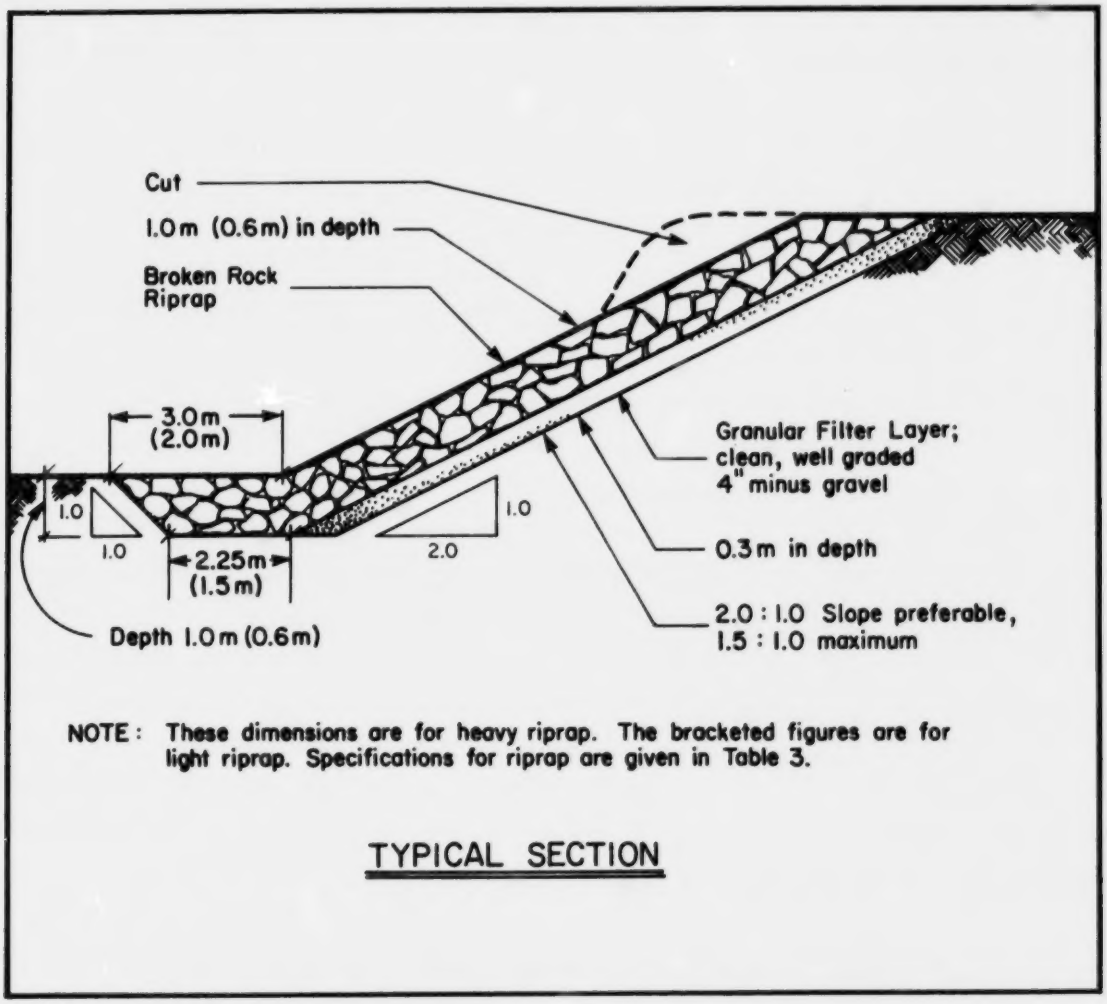

Cut
1.0m (0.6m) in depth
Broken Rock Riprap
3.0m (2.0m)
1.0
1.0
2.25m (1.5m)
2.0
1.0
Granular Filter Layer; clean, well graded 4" minus gravel
0.3m in depth
2.0 : 1.0 Slope preferable, 1.5 : 1.0 maximum
Depth 1.0m (0.6m)
NOTE: These dimensions are for heavy riprap. The bracketed figures are for light riprap. Specifications for riprap are given in Table 3.
TYPICAL SECTION

FIGURE 3 Typical Riprap Installation Showing Key Trench and Filter Layer

TABLE 3

ROCK RIPRAP SPECIFICATIONS

LIGHT RIPRAP

% BY WEIGHT FINER THAN	MASS (kg)	APPROX. EQUIVALENT DIAMETER (mm)
100	300	660
NOT MORE THAN 50	140	450
NOT MORE THAN 10	5	150

HEAVY RIPRAP

% BY WEIGHT FINER THAN	MASS (kg)	APPROX. EQUIVALENT DIAMETER (mm)
100	1100	900
NOT MORE THAN 50	300	600
NOT MORE THAN 10	40	300

Rock Riprap Shall:

1. Consist of dense, durable, roughly equidimensional, angular pieces.
2. Be clean and reasonably well graded covering the complete allowable size range from every load leaving the quarry.
3. Be free from cracks, seams and other defects that would tend to increase unduly its deterioration from natural causes.
4. Be free of objectionable quantities of dirt, sand, clay and rock fines.
5. Be shaped such that neither the breadth nor thickness of any individual piece shall be less than one third of its length. Thin, flat pieces will not be permitted.

Riprap Placement:

1. Rock riprap shall be placed in such a manner as to produce a reasonably well graded mass of rock with the minimum practicable percentage of voids.
2. No rock shall protrude more than 30 cm above the design lines and grades.
3. The finished riprap shall be free from objectionable pockets of small stones and/or clusters of larger stones.

7.2 ABANDONMENT OF WATER CROSSINGS

Permanent abandonment of water crossings may entail dismantling some of the structures and implementing rehabilitative measures, such as revegetation, to restore the watercourse and surrounding area to their former states. Restoration or reclamation of an abandoned crossing site may be a condition of a Water Approval. Again, the timing of any instream work is an important consideration.

Procedures for abandonment:

a. When water crossings are no longer used and are to be abandoned remove all structures except pipelines. Specifically:
   i. Where pipelines are abandoned, it is preferable to leave them in place and to block off maintenance roads.
   ii. Remove culverts and open up stream crossings to prevent obstructions or erosion.

b. Whenever erosion may be a problem implement appropriate erosion control measures. Remove all the unstabilized fill material from the site and reslope and seed all unstable areas. Where erosion has occurred, contour the streambanks to as near original shape as possible; if very steep, mulch or seed them to enable vegetation to establish itself.

c. Take measures to prevent vehicular access across streams where crossing structures have been abandoned and removed.

d. If possible conduct an annual inspection for at least 2 years following the abandonment of a water crossing and closure of an access route to assess the effectiveness of construction and rehabilitation measures. Further remedial action may be necessary.

8. CULVERTS

When determining the appropriate type of water crossing the final decision is based on the need for a crossing structure, the hydrological conditions, the installation and maintenance costs and the natural resource value of the stream. The preferred alternative, from an environmental point of view is to bridge each stream, particularly if there is a known fisheries resource. However, there are many cases where a properly designed and installed culvert is appropriate as a water crossing, from both an environmental and economic point of view.

It is important to differentiate between drainage culverts and stream culverts. Drainage culverts are installed in a road grade to allow passage of surface runoff water which has been collected and channelled by the roadway ditches. There are no fish at this point and no fish passage criteria are applied to these culverts. Stream culverts are installed where the road crosses a natural watercourse; fish passage criteria may apply to a stream culvert. Contact the regional office of the provincial Fish and Wildlife Branch and the district office of the federal Department of Fisheries and Oceans for information regarding fish utilization of streams. All culverts must be installed in a manner which minimizes sedimentation as the downstream receiving water will eventually be fish bearing.

8.1 DESIGN CRITERIA

The main criterion for culvert design is that the pipe must adequately pass the required flow of water. In addition, the culvert must:

1. be structurally sound,
2. be cost-effective,
3. produce neither sedimentation nor scour,
4. allow debris passage, and
5. permit fish movement where required.

The sections which follow contain information on hydraulic and fisheries considerations for culvert design (Table 4), as well as some recommendations for debris passage.

8.1.1 HYDRAULIC CONSIDERATIONS

Permanent culvert installations must be designed for acceptance by the Water Management Branch in accordance with Water Approval or Water Licence requirements. Specific recommendations regarding design include the following:

a. Minimum culvert diameter of one-half meter.
b. Capacity to pass the 100-year instantaneous flood with ponding no higher than the top of the culvert.

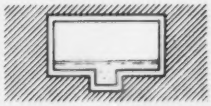
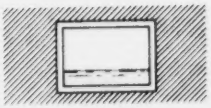
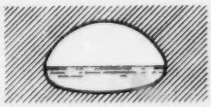
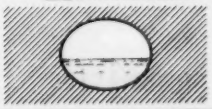
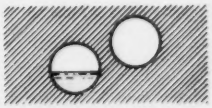
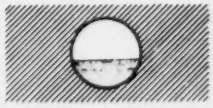
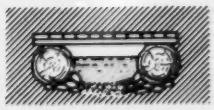
8.1.2 FISHERIES CONSIDERATIONS

Although all culverts must be properly designed and installed to prevent downstream impacts upon the aquatic environment, culverts used by fish require special design. Contact the regional office of the Fish and Wildlife Branch and the district office of the Department of Fisheries and Oceans to determine if and when fish use this stream system. Information regarding fish species present, fish age and swimming performance can be obtained at this time. Both this biological information and the hydrological characteristics of the stream are required to design an acceptable crossing structure.

A Department of Fisheries and Oceans report (Dane, 1978b) presents guidelines for the design and installation of culverts in British Columbia to avoid conflict with anadromous fish. Because of the large number of streams in British Columbia and the complexity of fish utilization, the design criteria presented therein cannot be applied directly to every situation and will have to be adapted to meet site-specific conditions.

TABLE 4

FISHERIES AND HYDRAULIC CONSIDERATIONS FOR VARIOUS TYPES OF CULVERTS
Adapted from Dane (1978a) and Wightman (1976)

TYPE OF CULVERT	FISHERIES CONSIDERATIONS	HYDRAULIC CONSIDERATIONS
1. OPEN BOTTOM PIPE ARCH	- If properly designed and installed, it does not limit fish passage. - Retains natural stream substrate. - Water velocities not significantly changed.	- Wide bottom area enables passage of high flows while minimizing increases in flow depth. - Large waterway opening for low clearance installations.
2. OPEN BOTTOM BOX CULVERT	- If properly designed and installed, it does not limit fish passage. - Retains natural stream substrate. - Water velocities not significantly changed.	- Can be designed to maintain normal width of the stream channel. - When a large end area is required in low fill, box culverts can be put side by side.
3. BOX CULVERT WITH TROUGH 	- Can be designed to provide fish passage. - Trough concentrates water maintaining fish passage even at low flows. - Baffles can easily be installed.	- Can be designed to maintain normal width of the stream channel. - When a large end area is required in low fill, box culverts can be put side by side. - Note: Trough can fill with bed load material and create maintenance problems.
4. BOX CULVERT 	- Acceptable for use with approved design in fish bearing streams. - Limits fish passage during low flow due to decreased flow depths. - Baffles can easily be installed.	- Can be designed to maintain normal width of the stream channel. - When a large end area is required in low fill, box culverts can be put side by side.
5. PIPE ARCH CULVERT 	- Acceptable for use with approved design in fish bearing streams. - Can be designed to retain some stream substrate. - Wide, flat profile makes it possible to improve fish passage by back watering the structure.	- Wide bottom area of culvert enables passage of high flows while minimizing increases in flow depth. - Large waterway opening for low clearance installations.
6. HORIZONTAL ELLIPTICAL CULVERT 	- Avoid use in fish bearing streams or incorporate appropriate design modifications. - Represents a compromise between pipe arch and round culvert cross sections. - Stream substrate not easily retained in culvert.	- Squat profile useful in low fill situations. - Shape results in deeper water depth than pipe arch, but does not offer as broad a bottom area.
7. STACKED CULVERTS 	- Allow for fish passage during wider range of flows than single culvert.	- Same hydraulic properties as type of single culvert used (Round, Box, etc.).
8. ROUND METAL CULVERT 	- Whenever possible, avoid use where fish passage is important. - If installed, incorporate approved design modification to permit fish passage. - High turbulence and other hydraulic properties greatly discourage fish passage. - Baffles are difficult to install.	- Generally constricts stream width and creates high flow velocities with increased chance of scour. - Concentrates water during low flows.
9. LOG CULVERT 	- If properly designed and installed, it does not limit fish passage. - Ensure proper decking to avoid introduction of sediment and debris into the stream. - Maintains natural stream bed and gradient.	- Exercise care not to restrict stream width. - Normally only used as a temporary facility.

The following section discusses important considerations for the design of culverts on fish-bearing streams. Consultation with personnel from the provincial Fish and Wildlife Branch and the Department of Fisheries and Oceans is essential before undertaking any detailed culvert reconnaissance, design or installation.

a. Design Criteria for Fish Passage

i. Maintain fish passage on any watercourse, regardless of size or whether perennial or intermittent, that is utilized by anadromous or resident fish during any period of the year.

ii. Where different species of fish or life stages of species are present, select design criteria that will accommodate all of them.

iii. The Ministry of Environment Regional Habitat Biologist and the Department of Fisheries and Oceans Area Senior Habitat Biologist or their designates will determine the necessity and design criteria for fish passage in culverts.

b. Water Velocities Within the Culvert

Excessive water velocities within or immediately up or downstream from a culvert can impede or block fish passage by exceeding the swimming ability of fish.

i. Wherever possible, select water velocities to provide fish passage on an individual stream basis. Consider the hydrological characteristics of the system, its fish species composition and the type of fish utilization of that stream.

ii. Slope is the most important factor determining water velocities in culverts. Keep culvert gradients as flat as possible to ensure fish passage.

c. Water Depth Within the Culvert

i. Water within the culvert must be of sufficient depth to completely submerge the largest fish to use the structure. Partial submergence prevents fish from generating maximum

propulsion and affects their oxygen intake by restricting gill functions.

ii. Minimum water depth within a culvert will vary depending upon species and size of fish, but should be no less than 8 cm during times of fish movement.

d. Water Surface Profile

i. Design culverts that avoid the creation of a sudden drop in the water surface profile. Sudden drops, such as elevated culvert outlets, become an obstruction to fish when the height of the water drop exceeds the jumping ability of the fish involved.

e. Migration Delay

Any interruption or interference of the fish's spawning cycle can affect the outcome of the spawning process.

i. Culvert installations designed for fish passage must function throughout a sufficiently wide range of flows to provide passage during the critical period of fish migration.

f. Culvert Length

The length of a culvert may occasionally replace water velocity as the major factor in fish passage because of behavioural characteristics unique to certain fish species. This situation is best determined on a site-specific basis by a qualified fisheries technician.

i. If possible, avoid the installation of culverts over 30 m in length at any gradient in fish-bearing streams. Topography, water velocity and fish productivity may further restrict maximum acceptable culvert length.

g. Culvert Installation Below Grade

i. In fish-bearing streams, install culverts with the bottom of the structure below the natural grade-line of the stream. Depth of placement below the existing streambed will depend

upon substrate type, anticipated flows, culvert size and location.

h. Prevention of Scour

There are various design features that prevent streambed scour and outlet drops on fish-bearing streams. Some of these features include:

i. Armouring the streambed at the outlet (Figure 4). Extend armouring (with riprap) at least 6 culvert diameters past the pipe exit, unless specially designed.

ii. Using artificial controls such as downstream rock or gabion weirs if bed scour cannot be controlled by armouring. These controls must allow fish passage.

i. Multiple Installations

If more than one culvert is to be used at a single crossing site, fish passage criteria need only be applied to one of them. The choice of culvert to which fish passage criteria will be applied depends on the discharge during the period of fish movement and the fish species involved.

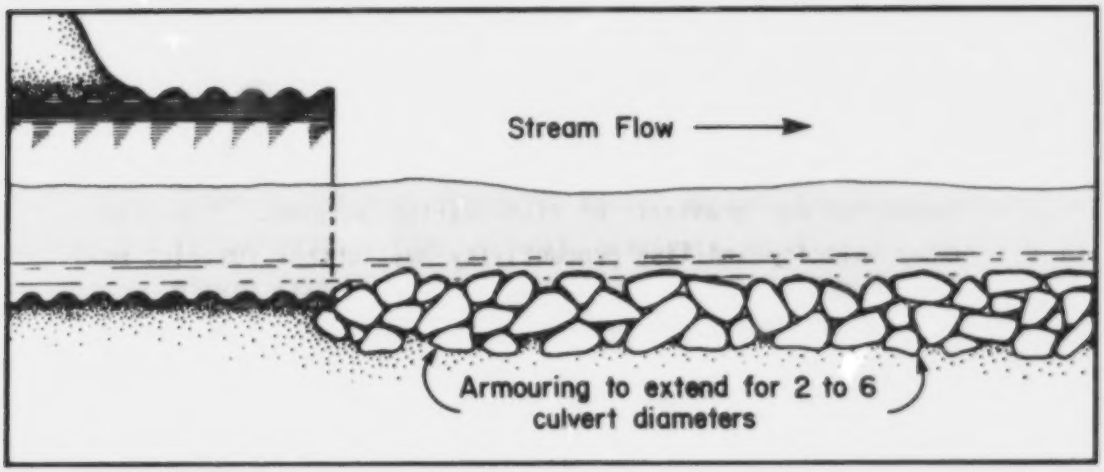


FIGURE 4 Armouring the Streambed to Prevent Scour

j. Fish Passage Structures and Aids

Special aids or fish passage structures may be required in situations where it is not possible to ensure fish passage with simple culvert installations.

i. One means of overcoming this problem is to use internal culvert baffles to provide rest areas for fish (Figure 5). Baffles are not generally used as they may catch debris. Baffles should only be used with approval from the Ministry of Environment and the Department of Fisheries and Oceans, and when other methods to reduce water velocities are not possible.

ii. An outlet pool incorporating a tailwater control device can be constructed at the downstream end of the culvert.

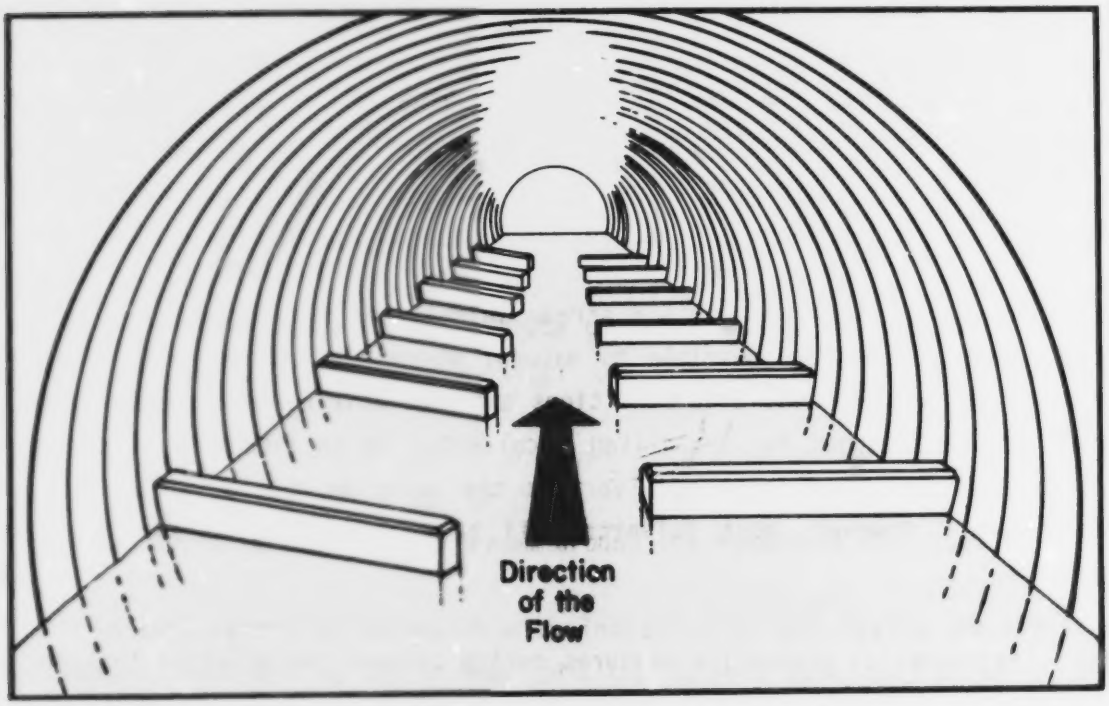


FIGURE 5 Culvert Baffles to Accommodate Fish Passage

8.1.3 DEBRIS PASSAGE

Culverts must also have sufficient capacity to allow for debris passage. If necessary, install debris control structures upstream from the culvert to prevent damage or culvert failure. However, such structures require maintenance throughout their life. Where debris movement is a common problem, consider other types of crossings such as a bridge.

In areas where culverts are subject to icing, the following measures will minimize or alleviate potential problems:

a. channel designs that ensure water surface area is not increased;
b. fabric fencing, timber walls or fencing upstream from the culvert to control icing before it reaches the crossing; and
c. stepped culverts to allow the passage of water through higher culverts if lower culverts have been blocked by ice.

Where measures are used to control debris or icing in fish-bearing streams, ensure such measures are designed to allow fish passage.

8.2 INSTALLING CULVERTS

It is important to maintain stream velocities, temperatures and sediment loads as close as possible to natural stream conditions while installing culverts. Specific site conditions and available equipment will determine the best method for installing a culvert. On an intermittent stream, it is desirable to place the culvert in the existing channel at a time of zero flow. However, most culverts will be placed while stream flow is present.

Environmental protection measures during culvert installation include:

a. Protect fish spawning and rearing areas from sediment resulting from construction. If necessary, construct settling basins to intercept waterborne silt before it reaches a stream.

b. Keep at least 1/3 of the width of the original flowing channel open during any instream work to allow fish to escape from the construction site.
c. Ensure that slash, dirt or other debris is not deposited into the stream or on the ice surface of any stream. Material that is toxic to fish or other life forms must not be discharged into the water nor placed where it can enter the stream.
d. Minimize the area subject to construction.

If a culvert is to be installed in a flowing stream channel, the water flow must be diverted around the work site during construction. Operations can then be conducted in a dry condition. Isolating the work site from the flow of water is the most effective way to control the release of silt and to minimize environmental disturbance. There are economic advantages to the use of this environmentally sound practice; it makes an easier and faster culvert installation and it may alleviate conflicts with resource agencies or downstream water users.

Accepted methods to control the stream flow may entail the use of one or a combination of the following:

a. a diversion ditch to re-route the flow around the work site;
b. a temporary culvert to carry the flow around or through the work site;
c. a pump with a properly screened intake to convey water in a hose around the work site; or
d. installation of a cofferdam around the immediate worksite.

In some cases, it is possible to install a culvert beside the existing streambed, redirecting the stream into the culvert upon completion of the installation.

Pumps withdrawing water from fish-bearing lakes or streams must have intakes screened in accordance with federal Fisheries specifications.

Methods used to control and divert the stream flow must ensure that the water is directed back into the original stream channel. If necessary, install suitable measures such as settling ponds to prevent the discharge of sediment-laden water into the stream.

Camber culverts under high fills to allow for the settlement of the fill. Cambering assures proper grade after settlement has taken place, thereby preventing sagging that might pocket water or sediment in the middle of the culvert. Generally, sufficient camber can be obtained by using a flatter grade on the upstream half of the structure than the downstream half.

Adequately protect the streambed and banks at both ends of the culvert to avoid erosion and sedimentation from turbulence and backeddies. Erosion control reduces the possibility of a culvert washout or channel realignment.

Erosion control measures:

a. Use riprap at the entrance and exit of a culvert. Other suitable materials for protection include rock baskets, gabions, fabri-form erosion control mats, baffles and deflectors.
b. Construct embankments with foreslopes not steeper than 1:1.75 or incorporate terracing. Use coarse, well-compacted materials for these slopes.
c. Install sediment traps or catch basins above and below the culvert to retain sediment.

8.3 MAINTAINING CULVERTS

Regular maintenance is required to keep culverts functioning properly and free of accumulated sediment and debris (Table 5). Inspection and maintenance are best carried out before the rainy season(s), before freeze-up and just after spring break-up periods. In sensitive areas, check culvert crossings during high runoff periods. Do not deposit debris or material

removed during clean up operations into a stream or in a place from which it may enter the stream.

Road maintenance equipment often damages or destroys culverts because the operator does not see them. Culverts should be staked, flagged or marked to prevent such damage.

TABLE 5

CULVERT MAINTENANCE CHECKLIST

Adapted from Bonser, Holmes and Sharpe (1977, pp. 10-13)

Culvert Entrance:

1. Dispose of floating debris which could be lifted by the headwater pool during a high flood.
2. Clear debris barriers.
3. Remove material from upstream settling basins or channels which may reduce capacity of culvert.
4. Backfill scour holes with clean gravel or larger rock.
5. Ensure that stream channel leads directly to the culvert entrance.
6. Repair or replace riprap alongside pipe to retain fills.
7. Tamp in material to prevent flow entering the fill surrounding the pipe.
8. Straighten metal entrance aprons.
9. Repair aprons and headwalls.
10. Cut brush and clear away debris at entrance.

Culvert Outlet:

1. Check for excessive scour.
2. Check pipes and endwalls for undermining; replace and protect bedding.
3. Replace riprap and ensure that it is large enough and extensive enough to protect the exit channel.
4. Check the downstream channel for blockages and scour.

Culvert Barrel:

1. Check for erosion of corrugated metal pipe, and replace damaged paved invert or coating.
2. Check corrugated metal pipe for corrosion.
3. Check concrete culverts for corrosion and erosion. Patches can be applied to old concrete with adhesives, and a small amount of work can prevent total failure.
4. Check the floor in concrete box culverts, as these are particularly subject to erosion and should be patched or replaced to prevent scour into the foundation.
5. Check wood staves for stave displacement.
6. Check all culverts for vertical and horizontal alignment, for distortion, and for open joints and leaks.

9. BRIDGES

9.1 PLANNING BRIDGE CROSSINGS

In planning any bridge crossing, several choices are made which dictate the effects that the bridge will have on the environment. These choices include:

1. the selection of a bridge site,
2. the type of bridge,
3. the type and location of the bridge substructure, and
4. the erosion and scour protection used.

9.1.1 SITE SELECTION

Factors such as the morphology of the river and its variation over time, the type of bed and bank materials, and the hydrological and hydraulic characteristics of the river, are all important considerations in site selection. In addition, the requirements of the area to be served and the economic and environmental factors must be considered.

The best bridge site is a narrow section of stream where the reaches above and below the proposed crossing are straight, have an even gradient and have little potential for debris jams. Ideally, a single span would cross the stream from abutments placed above the high-water mark on stable banks. Steep descents to a bridge are avoided to reduce hazard to bridge users, to reduce load impacts on bridge structure, and to minimize erosion in roadside ditches.

9.1.2 SELECTION OF BRIDGE TYPE

Having selected a site for the crossing, a bridge designer must then choose a type of bridge. This choice depends on the functional requirements

of the bridge, the economics of construction, live-load requirements, foundation conditions, environmental constraints, maintenance considerations, policies of the owner and preference of the project designer. Again, this report concentrates on the environmental implications of bridge choice.

The variables in bridge design include:

a. the geometry and length of the approaches.
b. the type and location of the abutments.
c. the number and location of the piers.
d. the depth to the footing supporting the piers to insure against danger from local scour.
e. the location of the encroachment in the floodplain.
f. the encroachment into the main channel.
g. the required river training works to insure that the river flows approach the crossing in an acceptable manner.

9.1.3 BRIDGE SUBSTRUCTURE

The choice of bridge substructure and the method of installation has the greatest environmental impact of any bridge building activity. Substructures and installation techniques are discussed below.

9.1.3.1 Waterway Opening

The waterway opening, which fixes the site of abutments and piers, is determined by stream size calculated at peak flow. Choose an opening to pass the design flood of a magnitude consistent with the type of crossing. If the bridge is to be permanent, if it is a high-cost structure, or if there are significant environmental values downstream, use a 100-year or greater flood to design the waterway opening. Major road bridges should have a one meter clearance above the 200-year, 24-hour flood event, with a sufficient normal clearance to avoid debris build-up. Take into account the amount of upstream ponding and the requirements for passage of ice and

debris. Consider also the effects of changes in the drainage basin, such as future logging.

If a substructure element, such as a concrete pier, would be in the flood channel, it is necessary to evaluate the potential effect of this obstruction and to determine the extent of local scour. Proper allowance for scour will prevent undermining of footings. Armouring against debris as well as erosion may be required. High stream velocities and frequent log or ice jams favour spanning the stream from bank to bank.

9.1.3.2 Abutments and Piers

The following three construction methods are commonly used to build abutments and piers in British Columbia:

1. building such structures from concrete,
2. using log cribs, and
3. driving or placing piles.

If a solid rock foundation is available, poured concrete structures are strongest, most erosion resistent and last longest. Even on gravel, sand or silt, concrete can be used if piles are driven first. Riprap must be used to protect these piles from scour. For instream work, divert or lower the water prior to any excavation at the pier site. If major erosion and sedimentation problems are anticipated, the work area may have to be isolated from the stream.

Log cribs should only be used for temporary bridges and should be completely removed at project abandonment. Where possible, avoid the use of log crib piers. Such pier installation requires instream work and disturbs the flow with resultant environmental effects. To help minimize environmental damage and ensure stability of log cribs:

a. Avoid positioning a crib on the outside curve of a stream.

b. Avoid constricting the stream between abutments or with instream piers.
c. Minimize crib pier width and prevent the accumulation of driftwood on the pier.
d. Place the lower crib logs deep enough below the streambed to prevent undermining by scour.
e. Backfill the lower section of the crib with clean, broken rock.
f. Place well graded riprap to extend around the structure and key such riprap to provide a protective apron below the streambed.

Pile type abutments and piers resist scour action better than do crib types if the piles are driven to the proper penetration. Gravelly soils are best for pile driving. Boulders make pile driving difficult but very often they form a shallow layer on the stream bed which can be removed to expose better pile driving soils. Any such boulder removal must be carried out in a manner that prevents downstream siltation. Consult with the regional Fish and Wildlife Branch and federal Fisheries Officers before attempting such procedures. Silts and clays are not good pile foundations; they may require long piles or mats for stabilization.

Ensure that creosote-treated lumber or materials are completely dry before use in or near any water body. Failure to dry such material will deposit toxic substances into the water.

9.1.4 RECREATIONAL AND VISUAL IMPACT

Bridges across fish-bearing streams are favourite access points for anglers. It may be desirable to provide off-road parking back from the bridge approaches and leave a path to the river bank. This will reduce traffic hazard to both bridge users and anglers and will prevent erosion of fill at the abutment due to foot traffic. Consult with the regional Fish and Wildlife Branch before undertaking such measures.

Where the river is used as a canoe route:

a. Cross the river with a free span if possible and design a 2 meter clearance above the normal high water level.
b. Re-establish vegetation to fill in the exposed gaps from the construction operation to minimize the crossing's visual impact from the water.

9.2 CONSTRUCTING BRIDGES

Bridges do not have to be completely constructed on site. Prefabricated structures that can be transported to the site are preferred as they minimize the work adjacent to the watercourse. Precast or prefabricated superstructures also avoid extensive formwork which is vulnerable to debris damage and they minimize the risk of concrete and lime pollution from cast-in-place structures.

The transportation of construction materials and equipment to and from the crossing site requires careful planning. Provide a material storage yard and turn-around site well back from the stream bank to prevent damage to riparian vegetation. It may not be permitted or possible to cross the river at the construction site and alternate routes are sometimes required to get materials and equipment to both sides of the river.

9.2.1 CONSTRUCTION PRACTICES

Even a properly designed bridge can have serious undesirable environmental effects if it is constructed in a careless or thoughtless manner.

Recommended procedures:

a. As much as possible, keep heavy equipment such as bulldozers, backhoes and cranes outside the high-water mark of all watercourses.
b. Excavate for piers, footings and abutments with the work area isolated from the flowing stream.

c. If instream work is permitted:

i. Use cofferdams of non-erodible material to separate work areas from streams.

ii. Do not block more than one-third of the stream width at any one time.

iii. Remove cofferdams upon completion of construction and restore the stream bed as directed by the Ministry of Environment Regional Habitat Protection Biologist.

Sheet metal cofferdams are preferred if bottom conditions permit their use. Such instream works can be detrimental to fish passage. Ensure that any temporary structures do not block channels in such a manner as to trap fish. If cofferdams affect the flow to an appreciable extent, upstream and downstream riverbank protection against erosion and undercutting may be required.

As a consequence of construction, many areas become highly susceptible to erosion. Bare unprotected bridge approaches, toes and fills will contribute to increased stream sedimentation if appropriate erosion control measures are not included in bridge design. Measures such as riprap, flexible mattresses, retards and spur dykes may be used but the extent of stream encroachment by these protective works must be carefully evaluated. Indiscriminate use can lead to scour and changes in stream cross section outside of the protected zone and possibly to failure of the protective blanket.

On wide flood plains, the lowering of approach fills to provide overflow sections designed to pass unusual floods over the roadway is a means of preventing loss of the structure. Where relief bridges are needed to maintain the natural flow distribution and reduce backwater, exercise caution in locating and proportioning the size of such structures to avoid undue scour or changes in the course of the main channel. Culverts may also be used to retain floodplain storage and prevent channelization.

9.3 MAINTAINING BRIDGES

A bridge requires frequent inspection and regular minor repair to increase its life and safety as well as to reduce the environmental impact due to its improper functioning. The following measures will help form such a maintenance program:

a. Conduct regular bridge inspections to determine any changes in the stream channel or deterioration of bridge structure. A full inspection is required annually, just after peak flow, as well as spot checks before and during any high flows.
b. Take depth recordings periodically around piers to assess scour and deposition. If excessive scour or streambank erosion is found, immediate action is necessary. Fill scour holes with clean, coarse material and protect with riprap. Stabilize streambanks and riprap as required.
c. Remove any debris caught on piers or abutments to prevent upstream flooding and to reduce stress on the crossing structure.
d. Ensure that roadside drainage and bridge deck drainage are working correctly to prevent erosion of approach ramps and sediment transport into the stream.

10. CAUSEWAYS

A causeway may act as a dam and affect the flow of water through a wetland or marsh. This in turn can disrupt the movement of aquatic species. By changing flow patterns and covering wetlands, causeways can also destroy fish and wildlife habitat. Long-term impacts on wetland vegetation are often more significant than short-term construction impacts. For example, strip clearing in a dense canopy opens up an area that can grow larger with time, far beyond the limits of original clearing. Dieback, windthrow, sunscald, cover type changes and drainage alterations are other long-term influences related to fills crossing wetlands.

10.1 DESIGN

To maintain the wetland habitat, it is necessary to preserve the water flows. In many instances, slow circulation is possible by seepage through a causeway constructed of coarse material. However, fish passage must be ensured by the installation of sufficient culverts (refer to section 8.1.2 for considerations regarding culverts and fish passage). In addition, provision must be made for passage of extreme flows. During high-water periods, both the direction and the velocity of the flow may be quite different from low flow times. Sufficient data must be gathered to ensure the water circulation is understood at all flows and taken into account in the design of drainage facilities. This means collecting data at all water levels and preferably for more than one year.

Culvert slope is even more critical in causeways through wetlands than in culverted streams. Fish utilizing the wetlands are generally juveniles (mainly fry) and may only be present for seasonal rearing so the culvert slope should not exceed 0.5% and velocities for passage should not exceed the swimming performance of fry. Fish passage criteria should be applied to culverts passing high flows as well as culverts for low flows in wetlands since juvenile fish movements in and out of wetlands may be correlated to changing water levels.

10.2 CONSTRUCTION

Suitable mitigation practices for causeway construction include the following:

a. Cross the shortest length of wetland possible with the least practicable habitat disruption.
b. Avoid activities that could contribute to sunscald, dieback, windthrow and erosion in forested wetlands.
c. Do not fill small wetland areas that are used by migrating waterfowl.
d. Prevent the obstruction of natural flow of streams or other surface waters by using equalizer culverts in roads across wetlands. Ensure fills do not interrupt flow patterns.
e. Prevent vegetation from entering watercourses.
f. Causeway construction material must be non-toxic to aquatic life and must not contribute to siltation. Dredged material is not normally acceptable as fill for causeways; use clean, granular material only.
g. Construct the causeway so that all material is contained within the proposed fill cross-section.
h. Ensure all causeway embankments are protected with riprap or other material to prevent scour or erosion due to waves, ice or currents.
i. Confine all heavy equipment to the causeway surface only. This will necessitate pushing a pad ahead as the construction operation advances. Bridge crossings may have to be approached from each side.
j. Any vehicles which are operated off the causeway surface must be of low bearing pressure type.
k. Confine support craft such as powerboats, airboats or hovercraft to operating within the right-of-way.
l. Use the same access route for all operations.

11. FORDS

11.1 USE OF FORDS

In limited circumstances, properly designed and constructed fords may be used as water crossings during periods of low water if permission from the Ministry of Environment and Federal Fisheries is obtained.

Fords or shallow water crossings may be used when the following conditions are met:

a. The streambed has a firm rock or coarse gravel bottom and the crossing site has stable approaches to support and withstand the traffic that will cross.
b. Crossing use is limited to the dry season, preferably when little or no water is flowing in the channel.
c. Debris could otherwise cause problems to bridges or culverts.
d. Rivers to be crossed are shallow (less than 1 meter deep).
e. Access to the crossing site is not on the outside of any bend in the watercourse.
f. The crossing will receive infrequent use.
g. Fisheries or water users downstream are not critical factors.

Installation of a ford usually entails minimal disturbance to the stream channel and surrounding vegetation. Concerns normally associated with culverts or bridges, such as size of waterway opening, provisions for debris passage and the need for channel or embankment riprap are largely avoided. In addition, the amount of required maintenance is normally less than for other types of crossings. In mountainous country, fords are particularly useful for crossing streams subject to dramatic increases in water level or "flash floods", where installation of a bridge or culvert would be very expensive.

There are, however, several major disadvantages to fording a stream. Crossing on an unstable streambed or unstable approaches will cause direct disturbance of the stream. Mudholes can form on the approaches and subsequent rains or traffic travel will discharge sediment into the stream. In addition, the washing of pollutants off equipment travelling through the stream is harmful to aquatic organisms.

11.2 DESIGN AND CONSTRUCTION

If fording through the stream is allowed, the following measures will reduce environmental impacts:

a. Make crossings at right angles to the stream, wherever possible.

b. Use only one crossing location, not more than 15 m wide and well marked to be visible to machinery operators.

c. Cross at sites that have stable approaches on both sides of the watercourse. If necessary, stabilize the approaches. To prevent silt tracking, use non-erodible material from the water's edge to 15 meters up the bank on both sides of the ford.

d. Provide sufficient adverse grade on the lower approach section to confine the stream to its channel even during periods of high water.

e. Use clean, coarse, granular material for instream fill.

f. After a ford is no longer required:

   i. Remove ramps in a manner and at times that will minimize damage to fish, wildlife and existing vegetation. Do not dispose of ramp materials within the stream or leave them within the high-water wetted perimeter.

   ii. Prior to final abandonment, stabilize or restore the stream bottom and banks to their original condition.

12. PIPELINES

12.1 PLANNING PIPELINE CROSSINGS

Once a pipeline route has been chosen, an analysis of the floodplain characteristics and substrate soils must be undertaken to properly design pipeline water crossings. The resource values present; the hydrologic and hydraulic characteristics of the stream; the streambank material, configuration and stability; and the substrate material all determine the appropriate crossing design and construction method to be used. Detailed contract specifications and drawings for each water crossing must be prepared well in advance of construction as part of the application for a Water Approval. Environmental factors which influence the design are discussed below.

12.1.1 DESIGN CONSIDERATIONS

Until recently, aerial pipeline crossings of major rivers or difficult sites were favored by pipeline companies; however, the buried pipeline crossing is now preferred as it is less subject to accidental or malicious damage. An overhead span is still an accepted method of traversing watercourses which have high resource values or those in environmentally sensitive areas. The installation of a prefabricated length of pipe spanning the stream and the excavation of the bank entirely from the land will minimize disturbance to the stream.

One of the major concerns for a buried pipeline crossing, in terms of reliability, is exposure of the pipe due to scour of the stream or changes in alignment of the channel. The depth of burial of a pipeline under a stream depends on a number of factors such as potential for scour, size and value of pipe, hydraulic properties of the stream, stream substrate, trench shape, and size of cover material (Figure 6). Similarly, the sag bend location or length of deep burial is determined by the potential for bank erosion. Exposure of the pipeline and subsequent scour downstream could

create an obstruction to upstream fish movement. It is also necessary to take into account ice jamming, storm surges or channel migration in calculating erosion and scour. Any river training works, other crossings or future possible changes in the basin must also be reflected in the design.

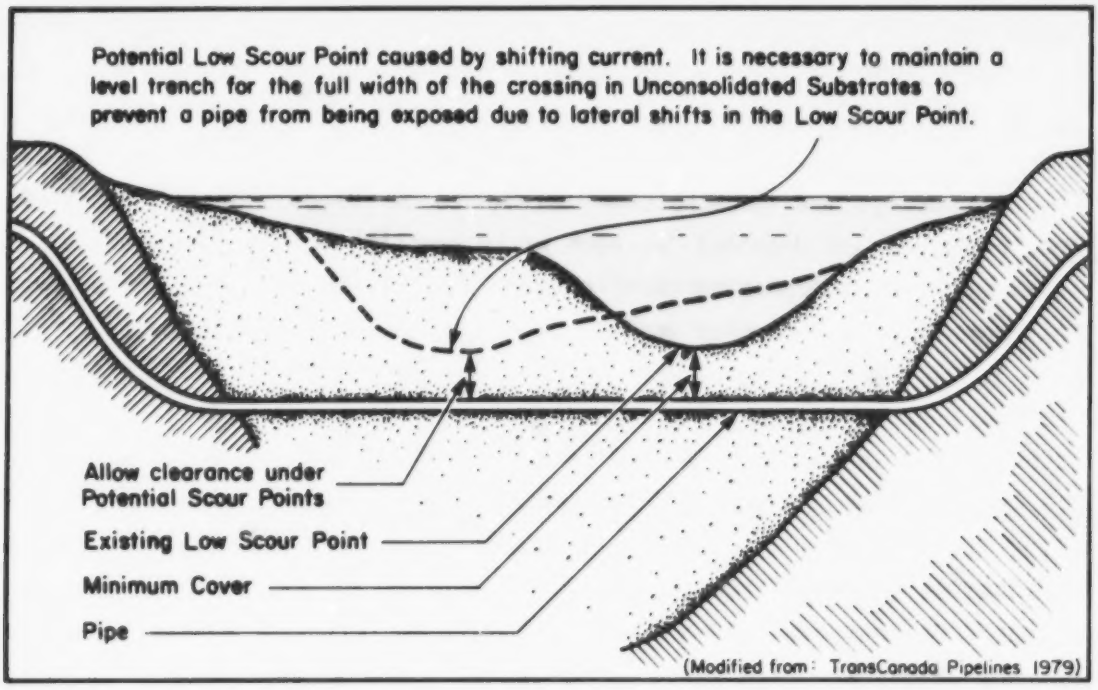

Potential Low Scour Point caused by shifting current. It is necessary to maintain a level trench for the full width of the crossing in Unconsolidated Substrates to prevent a pipe from being exposed due to lateral shifts in the Low Scour Point.
Allow clearance under Potential Scour Points
Existing Low Scour Point
Minimum Cover
Pipe
(Modified from: TransCanada Pipelines 1979)

FIGURE 6. Pipeline Crossing a Stream With an Active Substrate

Additional Recommended practices:

a. Adequately weight the pipeline to avoid instability due to buoyancy.

b. On wide floodplains, where the stream is highly braided, ensure deep burial of the pipe under the entire floodplain.

c. Deep burial may be necessary only under the main channel where:

   i. a single channel is entrenched with banks which are stable and infrequently overtopped;

   ii. channel cutoffs and downstream migration of meanders are not a problem.

d. If river training works are used to reduce the depth of deep burial, carefully design them to minimize the impact on spawning beds and other aquatic resources.

12.2 WETLANDS

Often pipelines cross regions of wet land or muskeg where the streamflow is not well defined or is mainly subsurface. While the pipeline work may not involve a distinct water crossing as such, particular care is required to maintain flow volumes and directions.

The following measures will minimize impacts when laying pipe through wetlands:

a. Do not divert streams or rivers outside their floodplain.
b. Exercise care to minimize changes in the meander pattern of streams.
c. Avoid gravel backfill for long stretches of trench or install impermeable blocks to prevent flow along the trench.
d. Where the pipeline trench crosses a wetland area and where the existence of this trench may drain the wetland, construct impermeable barriers on each side of the wetland.
e. Ensure that restoration measures minimize the changes to natural drainages; in particular, avoid the creation of new lakes or changes to the drainage of existing lakes or ponds.

12.3 CONSTRUCTION

12.3.1 GENERAL MITIGATIVE PRACTICES

To minimize environmental disturbance during pipeline construction:

a. Ensure that construction crews adhere to specific timing windows issued by regulatory agencies. To meet these requirements, it may

be necessary to install crossings separately from the mainline operation.

b. Prior to initiating construction at a water crossing, have all the necessary equipment and materials on site and ready for installation.

c. Just before starting any major construction activity within the wetted perimeter of a watercourse, contact a weather office for the weather forecast. Construction should not proceed if there is a probability of prolonged precipitation within the next few days.

d. Plan and conduct each water crossing so that the pipeline (at the water crossing site) is installed and protected with backfill in one continuous operation.

e. If the original elevation of the streambank cannot be retained due to loss of material, haul in and build up the bank with suitable, erosion-resistant materials.

f. Except for designated crossing sites, do not use any watercourse or dry streambed as an equipment or vehicle route. When it is necessary for equipment to cross or work in soft-bottomed rivers or streams, conduct these operations from working mats to minimize siltation.

g. Quite often, even though trenching takes place outside the wetted perimeter of the watercourse, siltation is created and still reaches the stream, many times in heavy concentrations. To reduce the discharge of sediment, isolate these non-wetted work areas from the main flow by:

   i. Leaving a plug of material in the trench at the water's edge, while the rest of the trench is being excavated. Remove this plug just before placing the pipe (Figure 7).

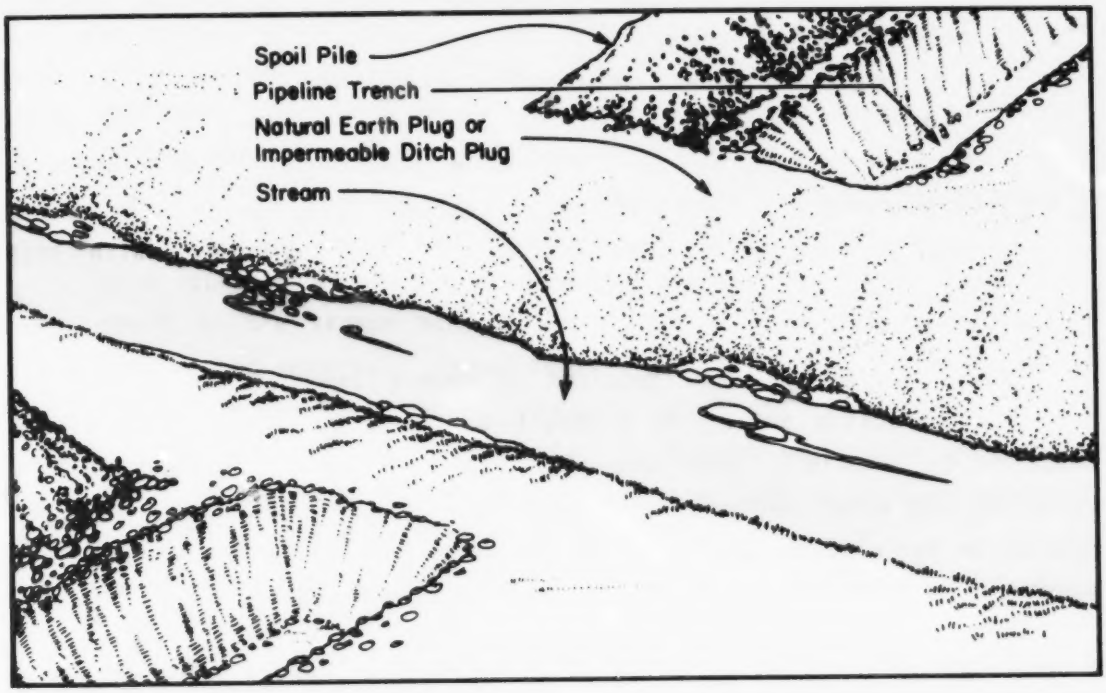


FIGURE 7 Leaving a Plug to Isolate the Trench
From the Main Channel During Excavation

ii. Putting an artificial barrier across the trench to prevent silt from moving back into the watercourse. Suggested materials for such a barrier include tarps (canvas, plastic, fabrene) which need a weighted bottom. If possible, pump the silt-laden water onto land for settling.

h. If backfilling with the original excavated material would cause excessive siltation, use clean, granular material to cover the pipe. Ensure that the backfill material does not create any ponding of the watercourse.

i. Where valuable fish habitat exists within the pipeline right-of-way, it may be necessary to replace any of that habitat which is destroyed during the pipeline installation. This may include placing large rocks in the stream, the reconstruction of overhanging or abrupt banks and the re-establishment of overhanging vegetation. Intensive rehabilitation, in consultation with regional fisheries agencies, is required in streams with high fisheries values.

Dewatering is sometimes required to remove impounded or groundwater from a construction area. As a result of exposure to various soils and construction materials, such impounded water may contain large concentrations of suspended sediment or may be contaminated with high nutrient content or toxic substances. Use the following techniques for dewatering to prevent such water from affecting the quality of watercourses:

a. Allow suspended sediments to settle before pumping water out of an impoundment. Remove settled solids after the water has been pumped out.
b. For small-scale operations, pump water onto stable vegetated ground away from the stream to allow for filtration of sediment. For major operations or continuous pumping of silt-laden water, construct a settling pond.
c. To reduce surface erosion when pumping, use energy dissipators that will ensure the water outlet does not cause gullying. Energy dissipators can include material such as a splash pad or diffusers on the outlet of a discharge hose.

12.3.2 APPROACHES TO STREAMS

Unless given special attention, pipeline approaches to streams can have adverse environmental effects. It is necessary to protect the riverbank from erosion and to prevent the direct flow of surface runoff from the approaches or pipeline trench into a watercourse.

Protection measures:

a. Minimize the vegetation removal from slopes leading to watercourses. Leave a minimum 15 m vegetation strip next to the watercourse until trenching and pipe-laying activities are ready to begin. If necessary, extend this vegetation buffer to cover areas subject to erosion from high water, such as floodplain slopes.

b. When approaching a water crossing, stop the pipe trench excavation short of the stream banks thereby leaving a protective plug of unexcavated material. Leave these plugs in place until the pipe-laying operation has begun. The plug length will vary depending on the specific crossing. Generally, a minimum plug width of 1 1/2 times the top width of the trench and in no case less than 3 m will be necessary on level ground.

c. Leave these plugs in place until completion of the instream excavation.

d. On hilly terrain consisting of erodible soils, minimize the time that the pipeline trench is left open. On the approaches to streams, backfill these trenches with stable material immediately after the pipe is laid. Install impermeable ditch plugs or breakers in sloped trenches to ensure that surface water does not flow through the backfill material in the trench (Figure 8).

e. Use suitable methods or devices on approaches to prevent runoff from entering the trench and to ensure that surface runoff is discharged to suitable settling areas. These methods or devices include the following: rolled cross trenches, boulders to diffuse water, crowning to run water off edges of right-of-way, removal of berms from edges of right-of-way to allow surface water to run into the vegetated slope, cross logs for slope stabilization, diversion berms, interceptor ditches and brush fences (Figure 9).

f. If, in spite of the above methods or devices, the introduction of silt is likely to occur, use structures such as cofferdams to allow these suspended sediments to settle out. Remove sediments or clean out structures as required.

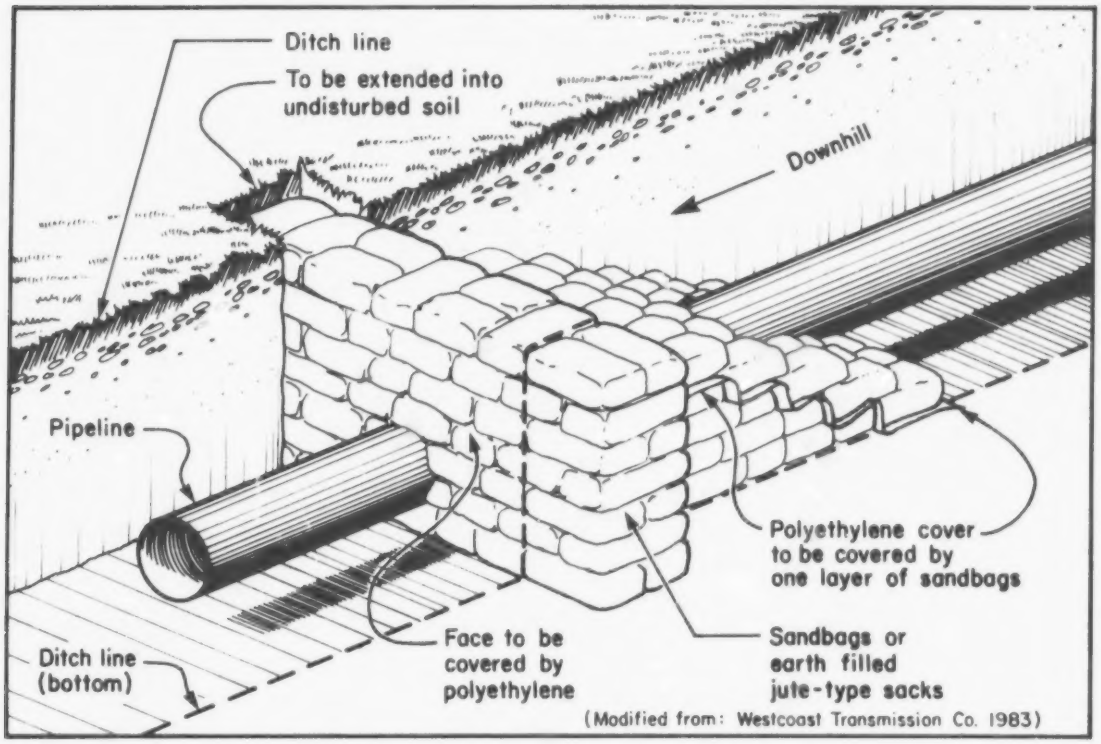

Ditch line
To be extended into undisturbed soil
Downhill
Pipeline
Polyethylene cover to be covered by one layer of sandbags
Face to be covered by polyethylene
Sandbags or earth filled jute-type sacks
Ditch line (bottom)
(Modified from: Westcoast Transmission Co. 1983)

FIGURE 8. Pipeline Trench Showing an Example of a Ditch Plug

12.4 SELECTION OF CROSSING METHOD

The choice of method for installing a pipeline watercrossing depends on the requirements of the pipeline system, economics of construction, engineering considerations and sensitivity of the stream. When crossing a stream, the environmental objective is to minimize disturbance to the stream flow and aquatic environment. In an intermittent stream, this is easily achieved by carrying out construction during no-flow times. On a perennial stream, "no disruption" involves an aerial or drilled pipe installation. The majority of pipes will be installed with some effect on the water flow. Installation is accomplished in a dry fashion by diverting the flow around the work site or by fluming the stream over the trench. Finally, many pipes are installed by means of actual instream excavation. The following

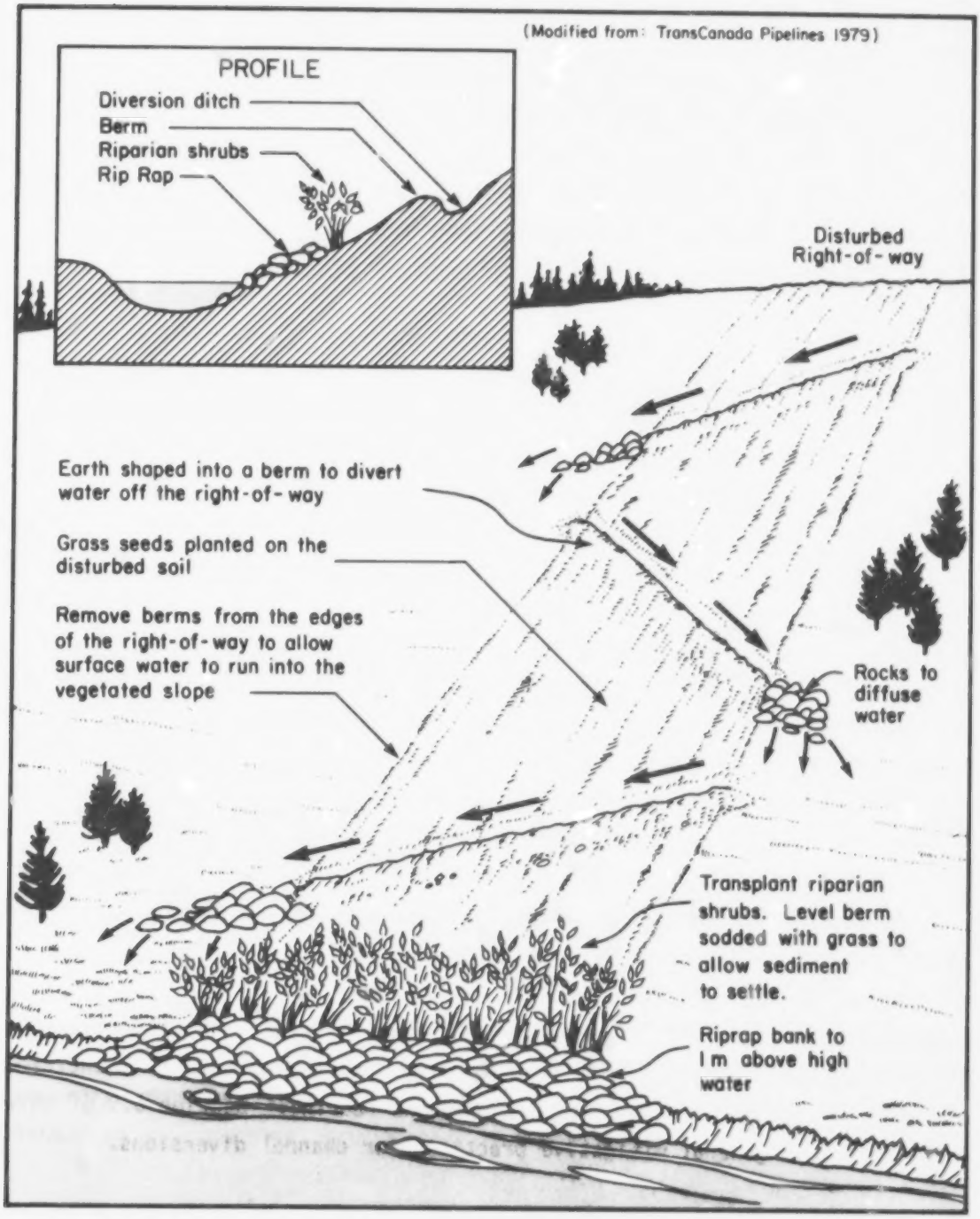

(Modified from: TransCanada Pipelines 1979)
PROFILE
Diversion ditch
Berm
Riparian shrubs
Rip Rap
Disturbed Right-of-way
Earth shaped into a berm to divert water off the right-of-way
Grass seeds planted on the disturbed soil
Remove berms from the edges of the right-of-way to allow surface water to run into the vegetated slope
Rocks to diffuse water
Transplant riparian shrubs. Level berm sodded with grass to allow sediment to settle.
Riprap bank to 1 m above high water

FIGURE 9 Erosion Control on Sloped Approaches to Streams

sections describe these various construction methods with procedures for minimizing environmental effects.

12.4.1 CROSSING DRY STREAMBEDS

Construction of buried pipeline crossings in intermittent or ephemeral streams can be scheduled for periods when there is no stream flow. The installation of such a "dry" crossing involves minimal disturbance to the stream environment.

The main concerns during construction are:

a. controlling seepage or sub-surface flows,
b. installing drainage structures for future access, and
c. ensuring that all waste from clearing and construction is pulled well back and placed outside of the high-water wetted perimeter.

It is important to completely restore and stabilize even this type of crossing as soon as possible after construction because an unexpected rainstorm or heavy precipitation event could turn a dry channel into a major stream.

12.4.2 STREAM FLOW DIVERSIONS

In special situations the main flow of a watercourse may be physically moved using a temporary diversion ditch, berms, dykes, an alternate existing channel or high-capacity pumps that allow work to proceed in the dry. Diversions can be difficult to do and require much forethought and planning. Stream diversions may not be allowed at sites and during periods identified as important for fish migration, spawning and rearing. Section 6.9 of this report provides general mitigative practices for channel diversions.

12.4.3 FLUMED CROSSINGS

The entire low flow of many streams can be flumed by one or more pipes through a crossing site. Generally, streams up to 3 m^3/sec (100 cfs) can be flumed. It is desirable that the timing of construction operations for fluming coincide with the low flow period. However, sensitive life stages or the presence of ice may be more critical to the timing than working at the lowest flow.

Fluming a watercourse enables trenching to be done in an area that is temporarily isolated from the main flow of water. It provides vehicular access across the watercourse, maintains relatively clean water during construction and enables work to proceed quickly and efficiently.

Flume types and installation procedures vary according to the design of each water crossing. The pipe must be large enough to handle the maximum flow of the stream to be controlled. It is essential that heavy steel pipes are used as flumes because corrugated culverts will not support the weight of water over the necessary distances. The length of the flume is dependent on the stability of the trench walls; the more unstable the bank, the longer the pipe. Ensure the ends of the flume are far enough from the trench to avoid undermining and collapse. Early testing of the substrate is required to design the flume installation and avoid situations of trench wall sloughing.

Leave the flume in place throughout as much of the excavation and backfill operation as possible. During backfill operations, pump water from the trench into a settling area. Exercise care during removal of flumes and temporary crossing structures to minimize damage to the streambed and banks.

12.4.4 WET CROSSINGS

There are watercourses that have physical characteristics or flow levels which make flumes or diversions impractical. In these situations it may be necessary to install the pipe "in the wet". Before using this method ensure that less damaging alternatives have been fully considered.

Wet crossings must be completed in the shortest possible time. Even though work is to proceed directly in the watercourse, careful designs and mitigative procedures are necessary. Sediment control measures should be developed on an individual stream basis in consultation with federal and provincial agencies.

Once a trench has been excavated, additional material may fall or settle back into the trench. Just before the pipe is laid this extra material has to be removed, usually with a crane or dragline. To reduce sediment from this source:

a. Have the excavating equipment provide extra width and depth when the trench is first dug.
b. Do not place excavated material so as to cause bank collapse.
c. During clamming operation leave a temporary barrier to separate the mainflow from the streambank excavation.
d. Ensure that clammed material is hauled away from the work site or deposited in an area where the excess water can be contained for settling out fines.

Where terrain instability is encountered during trenching, provide dewatering, bracing or other means to ensure the stability of the trench and side slopes. Take precautions to minimize bank erosion by using such materials as sheet piles or cribbing to create slack water without restricting downstream flow volumes.

12.4.5 DRILLED CROSSINGS

The installation of a pipeline by drilling or slip boring below the riverbed eliminates many of the environmental concerns associated with other pipe-laying methods.

The following summarizes some of the advantages of drilled river crossings:

a. Greater flexibility is achieved in scheduling operations. Year round construction schedules can be maintained because weather, hydraulic and environmental conditions have little effect on the installation.
b. The installed pipe is not subject to damage from anchors, erosion, dredging operations or vandalism.
c. Minimal disturbance in and around the stream makes it easier and faster to obtain approvals for construction.
d. Drilling eliminates bank restoration costs and concerns for habitat enhancement after construction.
e. Drilled crossings are almost maintenance-free for the life of the pipeline.

Further research is required to determine the feasibility and cost-effectiveness of drilled river crossings as compared to other types. Environmental and engineering costs associated with a river crossing may determine that such a method is cost-competitive.

12.5 OPERATION AND MAINTENANCE

At water crossings, many aspects of routine pipeline maintenance are important from an environmental point of view. Even though the pipeline itself may not be threatened, action may be required to control erosion or protect slope stability if environmental resources such as fish habitat or water quality are threatened. Therefore, a program of inspection and

maintenance is required along with well-prepared contingency plans. Early detection and correction of developing erosion problems will reduce environmental degradation and avoid environmentally disruptive emergency repairs.

Recommended practices:

a. Institute a regular inspection and monitoring program for all pipeline water crossings to determine:
   i. effectiveness of erosion control measures,
   ii. changes in water quality,
   iii. stability of streambanks, and
   iv. changes in streambed condition and morphology.
b. Inspect the water crossings:
   i. weekly during and for the first month after the freshet period,
   ii. monthly until the next low flow time,
   iii. quarterly thereafter for the life of the pipeline.
c. Act as soon as possible to correct serious erosion or instability problems. Smaller problems should be scheduled for repair during the least sensitive times.

12.5.1 CONTINGENCY PLANS

During construction and operation of the pipeline, establish strategies and procedures relating to:

a. Containment and clean-up of spills of fuels and other hazardous materials.
b. Repair of pipe failures, system malfunctions or potential malfunctions arising from such occurrences as earthquakes, slope failures, washouts, floods or forest fires.
c. Salvage of fish stranded or trapped as a result of construction activities.

These contingency plans must contain information regarding:

a. Pipeline repairs which would require immediate deployment of heavy equipment.
b. Timing of fish migrations and wildlife movements that could be placed at risk by pipeline activities.
c. Pipeline flaws which could be temporarily repaired during sensitive periods using low-impact procedures with more permanent repairs to be made subsequently during non-sensitive times.

13. GLOSSARY

ABUTMENT: the end support for the superstructure of a bridge. It has the function of transferring bridge load to the ground, retaining the approach fill and elevating the bridge to the required height.

ANADROMOUS FISH: of a stock or species of fish which reproduces in freshwater and migrates to salt or brackish water to rear for a portion of its life, usually achieving most of its growth in saltwater.

BLASTING: the fine division of rock or other material through the use of explosives.

BRIDGE: a deck for vehicle or foot traffic supported by abutments and/or piers. The dimension in the stream flow direction is generally less than the dimension perpendicular to stream flow.

CAUSEWAY: an embankment constructed through a body of water or over wetland. It usually includes culverts and/or bridges.

CLEARING: the cutting of all growth to within 30 cm of the natural ground surface and the removal and disposal of all trees, stumps, logs, rotten wood and other vegetative growth and rubbish from the area.

CULVERT: any conduit for conveying water through an embankment.

DRAINAGE CULVERTS: culverts designed to accomodate surface runoff which has been intercepted by a road grade or embankment.

EARTHWORK: an all-encompassing term used to describe the loading, hauling and spreading operations of road construction and the excavation and backfilling operations of pipeline installation.

FINES: bed or bank material less than 2 mm in diameter; includes sand, silt, clay and fine organic material.

FISH-BEARING STREAM: any water flow that is accessible to fish and capable of supporting aquatic life.

FLOODPLAIN: flat land bordering a river and subject to flooding.

FORD: any through-stream crossing for vehicles or equipment.

GRUBBING: the entire removal and disposal, usually by burning, of all stumps, roots and embedded logs, to a depth of 60 cm below the ground line.

GUIDEBANKS: structures to contain or reroute the flow of water. They are used instream to protect piers or abutments or to reduce the length of deep burial of a pipeline.

INTERMITTENT STREAM: a stream which has a defined stream channel and bank development and may appear to be dry during prolonged periods of little rain.

MARSH: wetlands that are periodically inundated to a depth of up to 2 m and that support an extensive cover of emergent, non-woody vegetation.

MULTISPAN: a bridge containing a pier or piers and more than one span.

PERENNIAL STREAM: a stream that maintains its flow throughout the year, in contrast to an intermittent one.

PIER: an intermediate support used to join and support the ends of two spans.

REVETMENT: a facing of stone, concrete or gabions placed on a natural bank or fill to guard against erosion.

RIFFLE: a shallow area of a stream, where the water surface is broken into waves by bed material wholly or partially submerged. A riffle may be drowned out at highwater.

SILL: an armouring layer of stone or other material placed on grade in a floodplain or stream channel to prevent scour of the streambed.

SPAN: is the unsupported distance between two successive structures such as abutments or piers.

SPUR: a dike or causeway extending into a stream to direct or alter streamflow.

STREAM CULVERTS: those culverts designed to accomodate natural, channelized water flow (creeks, streams, rivers).

STRIPPING: the removal from the construction area of all topsoil and organic material which is unsuitable for construction purposes. If this material is suitable for the growth of ground cover, it is generally stored for later spreading on sites which require revegetation.

SUBSTRUCTURE: abutments, piers, their foundations and protective works which form the bridge supporting structure.

SUPERSTRUCTURE: the entire structure of a bridge resting on the abutments and piers, consisting of stringers, trussing, decking and guardrails.

TEMPORARY CULVERT: any culvert which is not required to carry the annual freshet flow.

WETLANDS: transitional lands between terrestrial and aquatic systems where the water table is at or near the surface and the land is covered by shallow water at some time during the growing season.

14. BIBLIOGRAPHY

Alberta Fish and Wildlife Division. 1980. Fisheries Habitat Guidelines. Energy and Natural Resources, Edmonton, Alberta.

Alberta Natural Gas Company Ltd. 1979. Environmental Plans and Procedures Manual. The Alaska Highway Gas Pipeline Project, South B.C. Segment, Calgary, Alberta, 94 pp.

American Association of State Highway and Transportation Officials. 1976. A Design Guide for Wildlife Protection and Conservation for Transportation Facilities. Washington DC, 51 pp.

American Association of State Highway and Transportation Officials. 1977. Standard Specifications for Highway Bridges (Twelfth Edition). Washington DC, 496 pp.

American Iron and Steel Institute. 1971. Handbook of Steel Drainage and Highway Construction Projects (Second Edition). Washington DC, 348 pp.

Anderson, L. and M. Bryant. 1980. Fish Passage at Road Crossings: An Annotated Bibliography. Forest Service, United States Department of Agriculture, General Technical Report PNW-117, 10 pp.

Association of B.C. Professional Foresters and the Centre for Continuing Education, U.B.C. 1979. Drainage Structures for Logging Roads. Conference proceedings, 2 & 3 April 1979, Vancouver, 238 pp.

Bauer, A.M. 1970. A Guide to Site Development and Rehabilitation of Pits and Quarries. Ontario Ministry of Natural Resources, Toronto, Ont., Industrial Mineral Report 33, 62 pp.

B.C. Hydro. 1979. Cat Tracks and Water. Slide presentation, Vancouver.

B.C. Hydro. 1982. Transmission Line Projects Environmental Procedures Manual (Draft). Environmental and Socio-economic Services Branch, Vancouver, 113 pp.

Becker, B.C., D.B. Emerson and M.A. Nawrocki. 1974. Joint Construction Sediment Control Project. US Environmental Protection Agency, Office of Research and Development, Washington DC, Environmental Protection Technology Series EPA-660/2-73-035, 102 pp.

Becker, B.C. and T.R. Mills. 1972. Guidelines for Erosion and Sediment Control Planning and Implementation. US Environmental Protection Agency, Office of Research and Monitoring, Washington DC, Environmental Protection Technology Series EPA-R2-72-015, 228 pp.

Bell, M.C. 1973. Fisheries Handbook of Engineering Requirements and Biological Criteria. Requirements and Biological Criteria. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Bjornn, T.C. et al. 1977. Transport of Granitic Sediment in Streams and its Effects on Insects and Fish. University of Idaho, College of Forestry, Wildlife and Range Sciences, Moscow, Idaho, 43 pp.

Bjornn, T.C. and D.W. Reiser. 1979. Habitat Requirements of Anadromous Salmonids. University of Idaho, Moscow and U.S. Department of Agriculture, Portland, Oregon, Forest Service General Technical Report PNW-96, 54 pp.

Bonser, P.J., D.C. Holmes and W.M. Sharpe. 1977. Drainage 1. Highway Technology Training Program, British Columbia Institute of Technology, Burnaby, 346 pp.

3ritish Columbia Ministry of Energy, Mines and Petroleum Resources. 1980. Guidelines for Construction and Cleanup of Roads, Leases, and Seismic Lines in Petroleum Exploration Areas. Victoria, 83 pp.

Bryant, M.D. 1981. Evaluation of a Small Diameter Baffled Culvert for Passing Juvenile Salmonids. Forest Service, U.S. Department of Agriculture, Pacific Northwest Forest and Range Experiment Station, Juneau, Alaska, 8 pp.

Burns, J.E. 1970. The Importance of Streamside Vegetation to Trout and Salmon in British Columbia. Fish and Wildlife Branch, British Columbia Department of Recreation and Conservation, Nanaimo. 12 pp.

Carr, W.W. 1980. A Handbook for Forest Roadside Erosion Control in British Columbia. B.C. Ministry of Forests, Land Management Report Number 4, Victoria, 43 pp.

Case, A.B. and D.A. Rowe. 1978. Environmental Guidelines for Resource Road Construction. Forestry Service, Fisheries and Environment Canada, St. John's, Nfld., Report N-X-162, 41 pp.

Chamberlin, T.W. 1980. Aquatic Survey Terminology. Aquatic Studies Branch, B.C. Ministry of Environment, Victoria, APD Technical Paper 2, 30 pp.

Crown Zellerbach Canada Limited. 1973. Environmental Guide for Wood Supply Operations. 52 pp.

Curran, H.J. and H.M. Etter. 1976. Environmental Design for Northern Road Developments. Environmental Protection Service, Environment Canada, Ottawa, Report EPS 8-EC-76-3, 45 pp.

Dane, B.G. 1978a. A Review and Resolution of Fish Passage Problems at Culvert Sites in British Columbia. Fisheries and Marine Service, Pacific Region, Fisheries and Environment Canada, Vancouver, Technical Report No. 810, 126 pp.

Dane, B.G. 1978b. Culvert Guidelines: Recommendations for the Design and Installation of Culverts in British Columbia to Avoid Conflict with Anadromous Fish. Fisheries and Marine Service, Pacific Region, Fisheries and Environment Canada, Vancouver, Technical Report No. 811, 58 pp.

Dryden, R.L. and J.N. Stein. 1975. Guidelines for the Protection of the Fish Resources of the Northwest Territories During Highway Construction and Operations. Environment Canada, Fisheries and Marine Service, Central Region, Winnipeg, Man., Technical Report Series No. CEN/T-75-1, 32 pp.

Environment and Land Use Committee Secretariat. 1980. Requirements for Stage II Environmental and Socio-economic Impact Assessment of Foothills (North B.C.) Pipeline. Victoria, 26 pp.

Environmental Protection Agency. 1975. Logging Roads and Protection of Water Quality. Region X, Seattle, Washington, EPA 910/9-75-007, 312 pp.

Environmental Protection Service. 1977. Recommended Environmental Code of Good Practice for Gas Pipeline Development. Department of Fisheries and the Environment, Ottawa, Report EPS 1-EC-77-1, 56 pp.

Environmental Protection Service. 1977. Sarnia to Montreal Interprovincial Pipeline - Field Observations. Environment Canada, Environmental Design Division, EPS Ontario Region, Ottawa, MS Report No. O.R.-10, 118 pp.

Environmental Protection Service. 1977b. Recommended Environmental Standards for the Design and Construction of a Yukon Gas Pipeline. Fisheries and Environment Canada, Pacific and Northwest Regions, Vancouver, 67 pp.

Environmental Protection Service. 1978a. Recommended Environmental Practices for the Proposed Alaska Highway Gas Pipeline (Interim). Fisheries and Environment Canada, Pacific and Northwest Regions, Vancouver, Report EPS-1-PR-77-1, 70 pp.

Environmental Protection Service. 1978b. Analysis of Environmental Protection Activities for the Alaska Highway Gas Pipeline Project. Fisheries and Environment Canada, Ottawa, Report EPS-2-EC-77-1, 32 pp.

Environmental Protection Service. 1979. Environmental Code of Good Practice for Highways and Railways. Environment Canada, Ottawa, Report EPS 1-EC-79-2, 62 pp.

Environmental Protection Service. 1980a. Environmental Code of Good Practice for General Construction. Environment Canada, Ottawa, Report EPS 1-EC-80-1, 51 pp.

Environmental Protection Service. 1980b. Environmental Concerns and Recommendations: Alaska Highway Reconstruction and Maintenance, Kilometre 1008-1635. Environment Canada, Pacific Region, Report EPS 8-PR-80-1, 94 pp.

Environmental Protection Service. 1981. Proceedings of Resource Roads Workshops, Whitehorse and Yellowknife, March 16-20, 1981. Environment Canada, Ottawa, 255 pp.

Environmental Sciences Ltd. 1980. Aquatic Environmental Programs Southern British Columbia Pipeline Prebuild (Summary Report). Vancouver, 18 pp.

Fisheries and Marine Service. 1978. Guidelines for Land Development and Protection of the Aquatic Environment. Department of Fisheries and Oceans Canada, Pacific Region, 55 pp.

FitzGibbon, C. (ed). 1979. Environmental Protection Measures for the Development of Roads, Pipelines and Electrical Energy Transmission Lines. Saskatchewan Research Council, Saskatoon, SRC Report No. E79-3, 308 pp.

Forest Service. 1973. Protecting Fish Habitat During Forest Road Development. United States Department of Agriculture, California Region, Guidelines for Fish and Wildlife Habitats, Number Seven, 13 pp.

Forest Service. 1979. Roadway Drainage Guide for Installing Culverts to Accomodate Fish. Engineering and Aviation Management Division, United States Department of Agriculture, Alaska Region Report 42, 120 pp.

Gebhards, S. and J. Fisher. 1972. Fish Passage and Culvert Installations. Idaho Fish and Game Department, Boise, Idaho, 12 pp.

Gower, L.E. 1979. Maintenance and Inspection Considerations for Logging Bridges. Journal of Logging Management Reference Publication, Vancouver, 46 pp.

Harding, E.A. 1981. Suggested Procedures for Pipeline Construction Near or In Streams. Based on Pipeline Construction in the Coquihalla River Valley (Draft). Fish and Wildlife Branch, B.C. Ministry of Environment, Victoria, 39 pp.

Hetherington, E.D. 1974. The 25-Year Storm and Culvert Size: A Critical Appraisal. Canadian Forestry Service, Pacific Forest Research Centre, Victoria, Report BC-X-102, 27 pp.

Holmes, D.C. 1978. Manual for Roads and Transportation, Volume Two. British Columbia Institute of Technology, Forest Resource Technology, 58 pp.

Hooten, R.S. and D.S. Reid. 1975. Impact of Stream Channelization on Fish and Wildlife. Fish and Wildlife Branch, British Columbia Department of Recreation and Conservation, Victoria, 15 pp.

Hough, Stansbury and Associates Limited. Undated. Design Guidelines for Forest Management. Ontario Ministry of Natural Resources, Toronto.

Hoyer, G.A. 1977. Fish Passage at Culverts. British Columbia Fish and Wildlife Branch, Region V, Cariboo, Technical Report HP-77-2, 5 pp.

Jaffe, L. 1975. Stream Protection Guidelines for Subdivisions. British Columbia Fish and Wildlife Branch, Victoria, 14 pp.

Johnson, L.W. 1978. Maintenance Considerations for Mainline Logging Roads. Journal of Logging Management, Vancouver, 66 pp.

Johnson, L.W. 1979. Drainage Considerations for Logging Roads. Journal of Logging Management Reference Publication, Vancouver, 66 pp.

Kochenderfer, J.N. 1970. Erosion Control on Logging Roads in the Appalachians. Forest Service, United States Department of Agriculture, Paper NE-158, 27 pp.

Langer, O.E. 1974. Effects of Sedimentation on Salmonid Stream Life. Fisheries and Marine Services, Vancouver, 20 pp.

Lantz, R.L. 1971. Guidelines for Stream Protection in Logging Operations. Oregon State Game Commission, Report of the Research Division, Portland, 29 pp.

Lauman, J.E. 1976. Salmonid Passage at Stream-road Crossings. Oregon Department of Fish and Wildlife, Environmental Management Section, Portland, 78 pp.

Leydecker, A.J. 1973. Use of Gabions for Low Water Crossings on Primitive or Secondary Forest Roads. U.S. Government Printing Office, 4 pp.

Lotspeich, F.B. 1971. Environmental Guidelines for Road Construction in Alaska. Environmental Protection Agency, Alaska Water Laboratory College, Report No. 1610 GOI 08/71.

Lotspeich, F.B. and A.E. Helmers. 1974. Environmental Guidelines for Development Roads in the Subarctic. National Environmental Research Center, U.S. Environmental Protection Agency, Corvallis, Oregon, 59 pp.

MacMillan Bloedel Limited. 1976. Protecting the Forest Environment, Volumes 1 and 2. Vancouver, 70 pp.

Martz, L.W. and I.A. Campbell. 1980. Effects of a pipeline right-of-way on sediment yields in the Spring Creek watershed, Alberta. Canadian Geotechnical Journal 17:361-368.

Mineral Resources Division. 1981. Guidelines for Coal Exploration. British Columbia Ministry of Energy, Mines and Petroleum Resources, Victoria, 79 pp.

Nagy, M.M., J.T. Trebett and G.V. Wellburn. 1980. Log Bridge Construction Handbook. Forest Engineering Research Institute of Canada, Vancouver, 421 pp.

National Council of the Paper Industry for Air and Stream Improvement (NCASI). 1979. A Review of Current Knowledge and Research on the Impact of Alternative Forest Management Practices on Receiving Water Quality. NCASI Stream Improvement Technical Bulletin No. 322, New York, 141 pp.

New York State Public Service Commission. 1974. Achieving Stream Protection in Electric and Gas Transmission Line Construction and Management. Office of Environmental Planning, Transmission Facilities Section, Albany, 63 pp.

Noggle, C. 1977. The Behavior and Physiological Effects of Suspended Sediment on Juvenile Salmonids. Fisheries Research Institute, University of Washington, Seattle, 8 pp.

Northern Pipeline Agency. 1979a. Yukon Environmental Terms, Conditions and Related Guidelines Alaska Highway Gas Pipeline (Draft II). Ottawa, 36 pp.

Northern Pipeline Agency. 1979b. Northern British Columbia Environmental Terms, Conditions and Related Guidelines Alaska Highway Gas Pipeline (Draft II). Ottawa, 72 pp.

Northern Pipeline Agency. 1979c. Alberta Environmental Terms and Conditions, Alaska Highway Gas Pipeline (Draft II). Ottawa, Ont., 21 pp.

Northern Pipeline Agency. 1979d. Saskatchewan Environmental Terms and Conditions, Alaska Highway Gas Pipeline (Draft II). Ottawa, Ont., 23 pp.

Northern Pipeline Agency. 1980. Northern Pipeline Socio-economic and Environmental Terms and Conditions for the Province of Alberta. Calgary, Alberta, 37 pp.

Northern Pipeline Agency. 1981. Northern Pipeline Socio-economic and Environmental Terms and Conditions for the Swift River Portion of the Pipeline in the Province of British Columbia Including Environmental Guidelines. Calgary, Alberta, 59 pp.

Northern Pipeline Agency. 1981a. Northern Pipeline Socio-economic and Environmental Terms and Conditions for Northern British Columbia Including Environmental Guidelines, Calgary, Alberta, 71 pp.

Northwest Hydraulic Consultants Ltd. 1978. River Engineering & Hydrology for the Pipeline Industry. Calgary, Alberta, 130 pp.

Northwood Pulp and Timber Ltd. Undated. Northwood Guide for Culvert Installation. Prince George, 16 pp.

Nova Corporation Alaska Project Division. 1980. Environmental Plans and Procedures Manual. The Alaska Highway Gas Pipeline Project, Alberta Segment, Agents for Foothills Pipe Lines (Alta.) Ltd., 137 pp.

Ontario Hydro. 1978. Guidelines for the Design, Installation and Maintenance of Corrugated Steel Culverts (revised). Hydraulic Generation and Transmission Division, Forestry Department, 42 pp.

Ontario Hydro. 1981. Construction and Site Restoration Guidelines for Transmission Facilities. 67 pp.

Ontario Ministry of the Environment. 1978. An Environmental Study of the Interprovincial Pipeline Ltd. Sarnia-Montreal Extension. Environmental Approvals Branch, Toronto, Ont., 121 pp.

Ontario Ministry of the Environment. 1981. General Guidelines for the Preparation of Environmental Assessments. Environmental Approvals Branch, 42 pp.

Ontario Ministry of the Environment. 1982. Environmental Considerations for Planning the Construction of Hydrocarbon Pipeline Facilities in the Province of Ontario (1st Ed.). Environmental Approvals Branch, Toronto, 36 pp.

Ontario Ministry of Transportation and Communications. 1978. New or Modified Roadway Water Crossings. Environmental Assessment Class B5, Provincial Roads Program, 46 pp.

Overman, M. 1968. Roads, Bridges and Tunnels; Modern Approaches to Road Engineering. Doubleday Science Series, Doubleday and Company, Garden City, New York.

Pollutech Pollution Advisory Services. 1976. Environmental Effects of Dredging Operations: A Literature Review. Environmental Protection Service, Pacific Region, Vancouver, 31 pp.

Province of B.C. 1978. Review of Impact Assessment Studies for Westcoast Transmission Ltd.'s Foothills (North B.C.) Pipeline Project Relative to Requirements of Guidelines for Linear Development. Victoria, 28 pp.

Quigley, T.M. 1981. Estimating contribution of overstory vegetation to stream surface shade. The Wildlife Society Bulletin 9(1), Spring, pp.22-27.

Richardson, E.V. et al. 1974. Highways in the River Environment: Hydraulic and Environmental Design Considerations. Civil Engineering Department, Colorado State University, Fort Collins.

Revill Associates. 1979. A Study of Stream Turbidity Induced by Certain Aspects of the Construction of Linear Facilities and the Consequent Effects on Fish. Belleville, Ontario, 64 pp.

Roche Associes Ltee. 1976. Environmental Guidelines for Power Transmission Lines (draft). Environment Canada, Environmental Protection Service, 150 pp.

Rothwell, R.L. 1967. Logging and Road Construction--Maintenance Rules for Better Watershed Management. Canada Department of Forestry and Rural Development, Forestry Branch, Calgary, Alberta, 20 pp.

Schwab, J.W. and W.J. Watt. 1981. Logging and Soil Disturbance on Steep Slopes in the Quesnel Highlands, Cariboo Forest Region. British Columbia Ministry of Forests, Victoria, Research Note No. 88, 15 pp.

Shea, M. and J.S. Mathers. 1978. An Annotated Bibliography on the Effects of Roads on Aquatic Systems. Fisheries Branch, Ministry of Natural Resources, Ontario, 54 pp.

Stalnaker, C.B. and J.L. Arnette (eds). 1976. Methodologies for the Determination of Stream Resource Requirements: An Assessment. Utah State University, Logan, Utah, 199 pp.

Stream Enhancement Research Committee. 1980. Stream Enhancement Guide. Department of Fisheries and Oceans, Canada, 82 pp.

Toews, D.A.A. and M.J. Brownlee. 1981. A Handbook for Fish Habitat Protection on Forest Lands in British Columbia. Department of Fisheries and Oceans, Canada, 173 pp.

TransCanada PipeLines. 1979. Environmental Protection Practices Handbook. Calgary, Alberta, 63 pp.

Vogel, B. 1980. The Impacts of Pipelines on Fish and Wildlife: An Annotated Bibliography. Northern Pipeline Agency, Calgary, Alberta, 77 pp.

Westcoast Transmission Company Limited. 1979. Procedures Manual for Environmental Engineering. 111 pp.

Westcoast Transmission Company Limited. 1979b. Alaska Highway Gas Pipeline Supplemental Report No. 1. Vancouver, 29 pp.

Westcoast Transmission Company Limited. 1983. Vancouver Island Procedures Manual. Volume 5, 97 pp.

Wightman, J.C. 1976. A Brief Summary of Fish Passage Problems at Culvert Installations with Special Reference to Swimming Performance. B.C. Fish and Wildlife Branch, Ministry of Recreation and Conservation, Victoria.

Wightman, J.C. and G.D. Taylor. 1976. Salmonid Swimming Performance in Relation to Passage through Culverts. British Columbia Fish and Wildlife Branch, Ministry of Recreation and Conservation, Victoria, 36 pp.

Young, J.A. 1978. Recommendations for Putting Roads to Bed for the Protection of Fish and Wildlife Resources. British Columbia Fish and Wildlife Branch, Region 5, Cariboo, Technical Report 78-HP-1.

POOR

QUALITY

ORIGINAL